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A FLOODPLAIN MANAGEMENT FRAMEWORK WITH STRUCTURAL AND NON-STRUCTURAL MEASURES

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A FLOODPLAIN MANAGEMENT FRAMEWORK WITH STRUCTURAL AND NONSTRUCTURAL MEASURES

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A Floodplain Management Framework With Structural and Nonstructural Measures

ABSTRACT

The report herein presented develops a decision framework and describes the results of an investigation of the economic potential of structural as well as nonstructural measures for a floodplain in Farmington, Connecticut. The analysis demonstrates the potential usefulness of operations research methods to flood zone decision makers. The report includes a review of the literature in part one. Part two develops the components of the decision framework. The regional application is treated in section three. The subsequent section discusses the distributional equity impacts of the alternative measures. Finally, some conclusions and implications are set out in Section five.

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1. Introduction

While flood damage reduction programs to date have relied rather exclusively on structural measures -- e.g., dams, levee systems, floodwalls -- there is a growing awareness of the potential of nonstructural measures as a part of such a program. This awareness has come in part with the realization that structural measures often provide a false sense of security to floodplain occupants and, as such, often result in increased flood damages contrary to their intended purpose. Floodplain land use management is one such nonstructural approach which should be considered.

Floodplain management is based upon a set of decision rules for the utilization of both water and land resources. The design of structural works can be regarded in the rather familiar context of problems in optimization of water resource systems, about which there is extensive literature. Land use plans can also be considered in the context of problems in optimal allocation of land to various employment. Unfortunately, the literature on land use planning (especially floodplain management) is not abundant.

To be sure, the construction of a comprehensive floodplain management plan which combines regulation of land use and control of floodwater through the use of structural measures is not a simple matter. Difficulties are encountered at many levels including problems of legal, administrative, and technical origin. However, the present focus regarding the design of such problems is on the methodology for incorporating both structural and nonstructural measures into the decision process.

With the exception of the framework provided here and its earlier treatments by Kaul and Willis [1974, 1975], the work of James and Day represents the current status of the methodological research for this particular type of problem. James developed an iterative routine for comparing various (discrete) combinations of structural works and floodplain land uses. The routine was designed to minimize the sum of flood protection costs, residual flood losses, and the opportunity cost of floodplain land. Most of the shortcomings of the approach were admitted by James. In short, the approach merely adds costs for pre-assigned alternative combinations of measures, compares the costs, and indicates the least expensive combination. As such, the framework fails to provide many of the well-known advantages of operations research techniques.

In the other previous framework, Day applies operations research techniques to the problem. The control variables include decisions with respect to flood proofing and site elevation[1/] as well as assignment of various parcels of land to alternative uses. The objective is to make such decisions so as to maximize economic rent. This "optimization" is provided by linear programming methods. More specifically, a planning horizon is divided into a predetermined set of decision periods with solutions found separately for each period where parameters for later periods are adjusted to reflect conditions resulting from solutions to earlier period problems.

Day's work represents an admirable first effort, although he recognizes the shortcomings and suggests that additional conceptual and empirical work

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[1/] For each parcel, these decisions are made exogenously to the decision framework.

is needed. Accordingly, the present purpose is to build upon Day's formulation in an effort to alleviate some of the major limitations.

Anticipating the development to follow, his framework is extended to better incorporate elements of uncertainty as well as price flexibility with respect to land used and interactions arising between assignments. Simultaneous solution for all periods is also introduced in such a way that early period decisions are not made completely without regard to conditions forecast for later periods. This decision framework is developed below along with a summary of the results of a regional application of this model. The remainder of this section reviews the relevant literature with respect to decisions under uncertainty, social welfare functions, the social rate of discount controversy, economic land rent concepts, some alternative flood damage reduction measures, and some optimizing techniques; and finally provides a brief description of the region under investigation.

1.1 *Decisions Under Uncertainty.* Planning of development on floodplains involves decisions about the distant as well as near future. A long term model for making economically efficient and socially and politically acceptable policies would always be preferable to a short term policy if uncertainty associated with the technical and behavioral coefficients did not increase with time. But where these increasing uncertainties are not taken into account while making optimal plans, short term plans might be better than the long term ones. While planning development on floodplains, the planner, however, should take a longer term perspective and as such he cannot afford to ignore these risk and uncertainty considerations. Since risk and uncertainty have a major role to play in decision making in floodplain management, a brief survey of the area is offered below.

"Risk" suggests the potential variability of the objective configuration of the events while "uncertainty" underlines our subjective lack of knowledge as to which configuration will obtain. There is one tradition in the literature that attempts to formulate a distinction between risk and uncertainty in terms of theory of probability. According to this tradition, when we do not know the specific outcome but do know its probability distribution we talk of "risk"; when we do not know even the probability distribution we are in the realm of "uncertainty". In fact, this distinction has proved to be sterile. And indeed, we cannot in practice act rationally without summarizing our information in the form of a probability distribution [Savage, 1965]. While these two words may have different connotations, no formal distinction has been made in the context of this study. Both terms have been used to express a situation in which the analysis requires us to take into account the possibility of a number of alternative outcomes and assign subjective or objective probabilities to each possible outcome or state of nature.

A number of measures of risk have been adduced, and at least three conceptual frameworks have been developed to treat the effects of uncertainty. These frameworks are: (i) the homogeneous risk class concept, (ii) the mean variance criterion for portfolio analysis, and (iii) the time-state preference model. The risk class concept is designed to treat decision making without requiring a general equilibrium model. The time-state preference framework is a very general treatment of uncertainty in the context of market equilibrium. The Markowitz mean-variance criterion has been widely used in portfolio selection. The mean-variance models are less abstract than the time preference models in assuming a particular measure of risk (variance) and a utility function that depends upon only two parameters (mean and variance). This concept is employed in the present analysis and is treated more fully in section 2.

In the literature, variance has been the most pervasive measure of risk -- its validity or lack of validity as a risk measure has been discussed extensively by researchers including Tobin [1958] and Fama [1963]. Yet another measure of risk (see Stone [1970]), called Generalized Risk Measure (GRM), is defined as the difference in the utility of expected future wealth and the expected utility of future wealth.

Mathematically it may be expressed as:

$$\phi = U(\overline{W}) - E(U(\tilde{W}))$$

where:

ϕ = generalized risk measure,

$\overline{W}$ = expected future wealth,

U = the utility function,

E = the expectation operator,

$\tilde{W}$ = future wealth

This measure is general in the sense that with a simple monotonic transformation, it can be shown to be related to risk premium as defined by Pratt [1964] and Arrow [1965].

The problems associated with decision making under uncertainty have been thoroughly examined in the statistical literature; among others by Luce and Raiffa [1958] and Pratt, Raiffa and Schlaifer [1965]. The problem may briefly be stated as:

A choice is to be made from a set of acts $[A_1, A_2, \ldots, A_n]$ but the relative desirability of each act depends on which "state of nature" prevails, i.e.

either S_1, S_2, S_3, ... or S_n. With respect to any decision problem, a set of "states of nature" is assumed to form a mutually exclusive and exhaustive listing of those aspects of nature which are relevant to this particular choice problem and about which the decision maker is uncertain. There are various criteria of decision making offered in the literature. These include:

(i) Maximum Risk Criterion
(ii) Minimax Risk Criterion
(iii) Pessimism Optimism Index Criterion of Hurwitz
(iv) Principle of Insufficient Reason

Arrow [1951] defined the problem of decision criteria in its general form as one of defining a fair method of amalgamating individual choices to yield social decisions. This method combines individual preference patterns over various states of affairs to generalize a single pattern for society as a whole.1/ The most obvious of the extensions of orthodox economic theory which embrace the concept of uncertainty is also the simplest. It consists simply of revising the usual certainty model so that expected returns become the object to be maximized when uncertainty enters the picture. This is one way of making uncertain situations appear certain. Statistical theory does trace its usefulness to the events for the long run. The mathematical expectation of risky returns would in the long run equal "certain returns".2/ As such, the argument runs, "Why worry about uncertainty?" However, the theory works only under the assumption that the events are mutually exclusive. In the

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1/ This concept has been elaborated in Section 1.2.

2/ The Central Limit Theorem states, "For a sequence $[X_n]$, n = 1, 2, ... of independent and identically distributed random variables $E(X) \rightarrow U$ provided E(X) exists."

present context, for example, development at a particular point in time is not independent of development at another time. There is substantial dissatisfaction, then, with the argument that expected returns maximization as a choice criterion is in general a rational behavior under uncertainty. This further gives rise, instead, to an a priori preference for the avoidance of risk.[3/] Following this argument, a rational being can be induced to increase risk only if his action is accompanied by a compensatory rise in expected value. In a formal sense, therefore, expected returns of any investment is discounted by some measure of risk. This, therefore, becomes a two parameter problem.

Markowitz [1952] rescued the certainty equivalence theme from this predicament. He demonstrated that the same mentality which motivates the certainty equivalence approach to risk -- i.e. a preference for expected value and an aversion towards risk -- can be shown to lead to development of a balanced or diversified portfolio. Markowitz must, in fact, receive the credit of first conceiving of this problem as a quadratic programming problem. He approached the problem by way of minimizing the portfolio variance. This, in fact, is another variant of the mean-variance model previously discussed. The same idea could be reformulated with a different objective criterion. The result is that one can visualize a number of criterion functions depending upon the type of the problem to be solved and the attitude of the decision maker towards risk.

1.2 *Social Welfare Functions*. Bergson [1938] defined a social welfare function, where individual utility functions enter as arguments, as:

3/ See Oi [1961].

$$W = W[U^1(X^1), U^2(X^2), U^3(X^3), \ldots, U^n(X^n)]$$

where $U^i(X^i)$ is the utility function of the individual i and $X^i = (X^i_1, X^i_2, \ldots, X^i_k)$ is a commodity vector. While defining a social welfare function, Bergson supposed that individual values were such as to yield a social value judgment. The social choice from any given environment as an aggregation of individual preferences is implicitly accepted by most such economists; e.g. Bergson [1938], Little [1952] and Arrow [1951]. However, whether it is possible to aggregate the individual preferences to reach a social choice has been long debated. Arrow [1950] addressed himself to this question. He argued that passing from individual to collective tastes fails to satisfy the condition of rationality. He clarifies his point of view while quoting a "paradox of voting". He further argued that there are preference patterns which, if held by the individual member of the society, will give rise to inconsistent patterns of social choice. The outcome is "Arrow's General Possibility Theorem". The striking result (Arrow [1951]) that when certain conditions implicitly imposed on the method of social choice by many writers are explicitly set down as axioms, they turn out to be inconsistent. More specifically, he argued that, in general, it is not possible to construct a social welfare function that satisfied these axioms:

(1) Complete Ordering. Social preferences should be defined for every combination of individual ordering.

(2) Responsiveness to Individual Preferences. It should bear a positive association to individual values.

(3) Non-imposition. Social preferences should not be imposed independently of individual preferences.

(4) Non-dictatorship. Social preferences should not be reflecting the preferences of any single individual.

(5) Independence of Irrelevant Alternatives. The most preferred state in a set of alternatives must be independent of the existence of other alternatives.

Blau [1957] pointed out the apparent weakness in Arrow's conditions which lead Blau to construct an explicit social welfare function satisfying all the conditions (1-5), hence, declaring the General Possibility Theorem to be incorrectly stated. He pointed out that if the first two conditions were slightly modified, the difficulty of constructing a social welfare function could be avoided. However, condition 1 as modified becomes a very strong (restrictive) condition which may not hold in the real world.

Inada [1964], while examining the weakness of these conditions which lead Arrow to his theorem, identified two more conditions in addition to Blau's conditions which would lead to the existence of social welfare function.

Sen [1966] generalized these restrictions under one theorem which he called "Possibility Theorem for Value-Restricted Preferences".[4] The theorem states that:

> "The method of majority decisions is a social welfare function satisfying Arrow's conditions 2-5 and the consistency conditions for any number of alternatives, provided the preferences of concerned individuals over every triple of alternatives is Value-Restricted and the number of concerned individuals for every triple is odd." [Sen (1966), p. 495]

Having discussed the existence of a social welfare function, it may be added that it is not necessary to assume the measurability of social welfare as with any type of economic efficiency criterion. In fact, what matters is the existence of a consistent social ordering of preferences. The objectives of economic efficiency may not necessarily lead to social welfare. Non-efficiency objectives at times may be better and more socially desirable than economic efficiency objectives. In decision making one oftentimes faces a situation where one cannot conclusively say which criteria to follow because each one leads to a specific goal. From economic, social, and political points of view, goals are oftentimes conflicting. To resolve the issue of decision making under such situations, various preference orderings need to be assigned some weights. The procedure of weighing these preferences has been discussed, among others, by McKean [1963], Mishan [1967], Marglin [1967], Eckstein [1961], and Haveman [1965].

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[4] A set of individual preferences over a triple of alternatives such that there exists one alternative and one value with the characteristic that the alternative never has that value in any individual's preference ordering is called a Value-Restricted Preference Pattern over that triple for those individuals [Sen (1966)].

1.3 *Social Discount Rate.* There has not been unanimity among researchers on the issue as to which rate of discount should be applied to public investment decisions. Various views appear on the proper use of the discount rate. We shall concentrate here on the major ones.

Official policy in the United States as established by the Green Book[5/] is to base public sector investment decisions on interest rates prevailing or expected to prevail in the market for government bonds. Hirshleifer, Dehaven and Stockfish [1968] proposed to discount benefits and costs at the estimated marginal productivity of capital in the private sector of the economy. Marglin [1963, pp. 95-112] and Sen [1967] are of the view that discount

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[5/] United States Government Federal Inter-Agency River Basin Committee, Sub-committee on Benefits and Costs, Proposed Practices for Economic Analysis of River Basin Projects (Green Book), Washington, May 1950, revised May 1958.

rates should take cognizance of some measure of social time preference. The social time preference position argues that the public sector should increase its own investment by adopting a discount rate which is below observed private sector rates -- a discount rate which reflects the social desire to provide for the future. They assert that market rate of interest gives an exaggerated picture of the rate of social time preference and as such suggest that the discount rate be such that it represents the consensus of the society as a whole. This issue remains controversial primarily because of the multitude of complex sub-issues with which it is entangled -- among them are the effect of taxes on real costs, the treatment of risk and uncertainty by the public sector, and the externalities created by long-lived investment.

Baumol [1968] argues that the "correct rate of discount for the evaluation of a government project is the percentage rate of return that the resources utilized would otherwise provide in the public sector". This opportunity cost concept depends on various factors such as the source of finance and the risky nature of the investment.

Economists, including Arrow [1964], Sen [1964], Seagrave [1970] and Marglin [1963], argue that the social rate of discount should invariably be lower than the private rate of interest which reflects the risk aversion behavior of the firm.[6]

As mentioned earlier, the externalities associated with any project, private or public, have a very important role to play in the calculation of the social rate of discount. The public projects yield positive externalities which are greater than the yield on its capital investment as compared to private investment projects whose externalities often provide negative benefits such that the social benefits are lower than the returns to capital. For example, associated with water development projects are the benefits that are recreational, environmental, etc. All these intangible benefits over and above the ones that the project is designed for need to be taken into consideration while calculating returns on capital investment on these projects. In public project undertaking, the object is to maximize the social benefits as compared to maximization of profits in private undertakings. As such due consideration needs to be given to externalities while deciding upon the social rate of discount. This is, in particular, true of developments in the floodplains and investments in flood control projects.

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[6] The "Theory of Large Numbers" suggests that the larger the number of projects involved the smaller the risk contributed to total social returns by way of them, provided these projects have independent prospects of success. As such, from society's point of view, taken as a whole, these investments become riskless.

1.4 *Economic Rent of Land.* A number of theoretical treatments of land rent and land value appear in the literature.[7] Some of the relevant considerations are described below.

Rents discussed in the literature refer to either site rent or land quality rent or both. Traditional approaches to real estate economics envisions various factors which structure the pattern of site rent. These include: (i) locational influences, (ii) legal or custom based restrictions on land use, and (iii) amenities. All these have an effect on land rents.

In the absence of serious market imperfections, the price of land will reflect the capitalization of the anticipated future flow of net rent.

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[7] Marshal [1930] examines the question of land rent and land value at some length. More recent discussions are found in Ralph Turvey [1957].

Until the time of development, the capitalization process suggests a time path for land prices -- the concept that shall be followed in the present study. The distinguishing characteristic of vacant land is that up to the time it is developed, the return to the owner is zero. Assume "V" to be the value of land at the time of development "t". (V itself would, of course, be the present worth of an expected series of net returns.) Let the appropriate rate of discount be "i". Then the present worth "P", assuming continuous discounting would be given by the relation (1.1).

$$(1.1)\quad P = V \cdot e^{-it}$$

where e is the base for Naperian logarithms. The relative rate of change of the present value with respect to time t will be:

$$(1)\quad \frac{dP/dt}{P} = -i \text{ or } -(i+r)$$

where r is the real estate taxation rate. Seen the other way, as one approaches the development date, the price of land can be expected to grow at the rate (i+r), where i corresponds to the net rate of return which can be earned on other comparable investments. It should be emphasized that this is entirely the result of capitalization and discounting. In the words of Clawson [1962, p. 104]:

> "If there is complete knowledge as to the time of future conversion, as to the value at that time, as to holding cost and as to discount rate, then obviously every one would be in complete accord as to present worth. There would be no opportunity for speculative gain, because all future values would have been fully and accurately discounted into present value."

In relating observed rises in the prices of land over time to changes in conditions like growth of demand for land, one has to be a little cautious. To the extent that such growth has been foreseen it will be built into property values at the beginning of the period considered and will not influence the movement of price over time. This argument has been well supported in the theoretical literature by such researchers as: Czamanski [1965], Ratcliff [1961], and Alonso [1964]. Theoretically if the development of land has been anticipated, the price of undeveloped land would tend to follow a time path determined by the discounting of its value at development under the prevailing interest rate. Changes in expectations, interest rates and holding costs, and market imperfections will result in divergence of prices from this path. Empirical support has been found in Adams, et. al. [1969] who conducted a study in Northeastern Philadelphia.

Petrakov and Kharahrov [1971] while arguing for the economic evaluation of land say that the proper approach to rationalization of land use is complex and as such they favor the criterion of economic evaluation of rent in the form of "differential rent or its capitalized form". Capitalization of rent represents a summation of discounted rents over time. If we assume that the economic rent and the capitalization norm remains constant over time, the following equation yields rents in monetary terms:

$$(1.3)\quad R = \sum_t [P/(1+i)^t] = P/i$$

where R is the capitalized land rent in monetary terms, P is the annual economic rent and i is the capitalization norm.

1.5 *Alternative Flood Damage Reduction Measures.*

The role and importance of the major structural and non-structural flood damage reduction measures are treated briefly below.

1.5.1 *Flood Warning Systems.*

The role of flood warning systems in the reduction of the flood damages due to deaths and damages to the structure built upon the floodplains has been discussed in the literature, although no systematic attempt has been made to evaluate the benefits due to warning systems. The single attempt that has been made in this direction is by Day, et. al. [1969]. Benefits due to warning were considered as the reduction in damages due to warning. Benefits were considered to be a function of time of warning as it related to the evacuation of contents (property) and the saving of lives. Since both public and private costs of warning service and cost of evacuation and reoccupation are incurred in the action, the net benefits are measured as the difference between the expected damages without a warning system and expected damages with a given warning system. The annual expected damages are calculated using the equation (1.4):

$$(1.4) \quad E(D) = \sum_{i=1}^{n} P_i D_i$$

where P_i refers to a probability of occurrence of a flood at the second level of intensity, D_i is community damages associated with flood level i and is treated as a function of warning type, type of action, and response to the warning. The authors have shown that benefits vary in accordance with the type of development that takes place on the floodplains. Looking carefully at the cost components of the warning system, one can visualize the difficulty involved in the calculation of private costs of evacuation and reoccupation. Benefits as perceived by the authors can be thought of as having been taken into account to a large extent by calculating the damage reduction due to flood proofing of various kinds. The greatest benefit of a flood warning system, however, may be in the reduction of loss of life. This aspect has been ignored by these authors.

1.5.2 *Flood Proofing*. Flood proofing, as one of the structural measures of flood damage reduction, is defined by Sheaffer [1960, p. 3], as "a body of adjustments to structures and building contents which are designed or adapted primarily to reduce flood damages". It may include building with such materials or various methods of construction which are less susceptible to flood damages, sealing of walls to control seepage, permanent closures of unnecessary openings, higher structural elevation, etc. These measures of flood proofing the structures can be made effective through legal controls such as building codes for building on floodplains. This opens up an alternative for structural measures. How far can this be treated as an alternative is a question that needs economic analysis vis-a-vis other measures.

Flood proofing first entered the flood damage reduction literature with the pioneering work of Sheaffer [1960]. He classified the various types of flood proofing under three broad categories:

(i) Permanent Measures -- designed to protect against the flood. These are not dependent upon any judgment after installation, forecast or action to put into effect.

(ii) Contingent Measures -- measures that are not effective until receipt of a warning. These are, in fact, conditional upon flood forecasts and flood warnings.

(iii) Emergency Measures -- These are either improvised during an actual flood or are undertaken according to the prior emergency plans of action. These include use of sandbags in the event of a flood and may better be classified as last minute rescue efforts.

James [1967] studied the economic feasibility of such a measure in juxtaposition with other measures. He considered flood proofing both from an engineering point of view and also its economic feasibility while working out the alternative measures of flood control. His optimizing calculations revealed that channels, proofing and location adjustments could each be associated with a characteristic situation for which it would be the measure of least economic cost. He found its justification in situations involving a low density of urban development and rather frequent flooding. His study showed that the maximum urban development within the floodplains for economic flood proofing was about ten percent.

Bhavnagri, et. al. [1966] provided a mathematical theory of flood damages which treats damages in a stochastic framework. They defined the measures of flood proofing as "static" and "dynamic" corresponding to the "permanent" and "contingent" categories defined by Sheaffer. The treatment of dynamic flood proofing has been stochastic. These authors were the first to introduce the uncertainty aspect of the flood damages in the flood reduction program on a theoretical or conceptual basis.

Willis and Aklilu [1973] studied flood proofing decisions under uncertainty and followed through with an empirical application. They provided a formulation for estimating means and variances of net benefits of flood proofing in a partial equilibrium context. The analysis of uncertainty in a decision making context for flood proofing utilizes the well-known E-V approach for a selected floodplain on the Connecticut River Basin.

1.5.3 *Flood Insurance*. After 15 years of work in developing a federal insurance program, Congress passed the National Flood Insurance Act of 1968 (Title XII of the Housing and Urban Development Act of 1968). Flood insurance and its relevance to a flood damage reduction program has been studied widely in the theoretical literature. Lind [1967] studied the economics of alternative measures of flood control. Besides discussing the correct measure of the benefits from land enhancement, he addressed the role of flood insurance in an overall program of flood protection. Lind considered various types of insurance and discussed some practical problems associated with each of these. It was argued that no insurance program in practice can provide complete protection and the premiums would not hold exact relationships to the expected value of losses except in the case where government runs the program and is ready to absorb the difference between the estimated value of losses and the true losses.

Krutilla [1966] advocated a federal flood insurance program which was slightly different from the one finally enacted. He proposed that the insurance be mandatory, pointing out that the net effects of flood control legislation had been to cause flood damage potential to increase even after $6 billion had been spent. The flood control act passed does not directly restrict floodplain development because it is not mandatory.

Vaut [1974] provided a comprehensive literature survey of theories of risk aversion and examined their relationship under various forms of utility functions. He further investigated the relevance of these theories to the National Flood Insurance Programs. It was shown that the concept of expected utility maximization, as modified by lexicographic preferences, served to best characterize the individual behavior under uncertainty associated with flood hazards. Further arguments were presented to support the levels of both private and public involvement in the National Flood Insurance program.

1.5.4 *Floodplain Zoning*. Floodplain zoning is an increasingly important tool for policy makers who have to deal with the rising claims from flood damages. Sheaffer [1960] and White [1958] have provided the reasons for people occupying the floodplains. In some cases, individuals continue building on floodplains even when they know the devastating effects of floods. They forget the past and are attracted by the environmental and other benefits of building on floodplains. Some occupants are not aware of the flood hazards in these areas. At the same time, building on floodplains also creates externalities for those who live upstream and downstream by way of raising the depth and intensity of floods. The rest of the society; i.e. those who live upstream; should be protected from the acts of individuals which infringe upon others. As such, justification for floodplain zoning is fundamentally the same as for any other constraint imposed by a society on its members.

Zoning does not mean prohibiting the use of floodplains but should be designed to enhance and not destroy the productive potential of floodplains. The decision to regulate land use becomes, then, a policy for optimum use of the resources.

Whipple [1969] considered floodplain zoning the only general alternative to structural flood control measures. He proceeded to determine how investment may be optimized between these two alternatives. He suggested that an optimum plan for the use of land within the floodplain zone may reveal a combination of structural methods and zoning if the floodplain is fairly varied insofar as flood risks are concerned, summarizing (p. 765), "The dichotomy of flood control and/or zoning is apt to lead to unproductive limiting cases on the optimization surface."

Day [1972] and Smiarowski, *et. al.* [1974], while planning land use on floodplains in certain communities, have shown that there are net benefits associated with some uses in certain locations in floodplains if the floodplain development is planned in an optimal way.

1.6 *Optimizing Techniques*. Having discussed the various criteria for decision making, some of the available techniques for optimizing the criterion function are reviewed.

1.6.1 *Benefit Cost Analysis*. Benefit cost analysis implies the enumeration and evaluation of all the relevant costs and benefits that are associated with a particular investment. After evaluating all the components of benefits and costs, two concepts for project evaluation are generally used: (i) the ratio of benefits to costs (B/C), and/or (ii) the difference between benefits and costs (B-C). Any ratio greater than one, for example, presumably qualifies as an economic investment. Ranking of the projects on the basis of this ratio could help in selecting these projects.

The first systematic attempt to apply benefit cost analysis to public economic decisions was a result of the expansion of public investment activity in the United States, especially in water resources development during the 1930's. A key document in the development of benefit cost analysis was the Flood Control Act of 1936, which stated that "the benefits to whomsoever they may accue [be] in excess of the estimated costs" should be the criterion for evaluation of public projects. Which benefits and which costs should be taken into consideration remained a matter of subjective judgment of policy makers. As a result there was no general agreement regarding the objectivity of the analysis. Many researchers have discussed this problem at length. Eckstein [1958], Steiner [1969], Marglin [1967] and Feldstein [1964].

By definition, present investment yields its return only as the future unfolds. As a result, all investments are, therefore, uncertain. But benefit cost analysis typically employs the artificial model of a world of certainty. The advances that have been made by theoretical economists in the past decade in the field of risk and uncertainty associated with any investment planning have not yet been fully absorbed by the economists who specialize in the field of benefit cost analysis. Secondly, the objectives of most public programs are complex. Benefit cost analysis which attempts to meet only one objective, i.e. of economic efficiency is largely irrelevant (Maass [1966]). Public programs are not based on the goal of economic efficiency only but have several other goals that are not generally treated in this analysis.

The advancement of operations research and its application in economic decision making have made many tools available that make it possible to meet social, economic, political and legal objectives simultaneously through a set of constraints imposed on the objective function.

1.6.2 *Programming Techniques.* Mathematical programming has provided powerful tools used by economists in the field of applied research. These techniques attempt to maximize or minimize the objective function criterion subject to various constraints -- economic, social, political, legal, or other. The functions used can be either linear or non-linear, continuous, discrete or mixed. This possibility of handling various functional forms makes the technique widely applicable. The various developments in this field have made it possible to recognize the stochastic nature of the coefficients of the model.

Considerable literature is available in the field of stochastic programming with linear or non-linear objective functions; e.g. Charnes and Cooper [1959, 1962]; Arrow, Hurwitz and Uzawa [1958]; Beal [1959]; Dantzig [1955]; Sengupta [1968] and Simon [1956]. It has been shown that the objective functional coefficients under the assumption of uncertainty can be treated as stochastic variables or the constraints can be framed in a probabilistic framework. These additional characteristics emphasize the advantages of programming techniques over the traditional benefit cost analysis. Markowitz [1952] demonstrated that the risky nature of investment portfolio can be captured by tackling the problem through mathematical programming.

Post-optimization plays an important role in the context of decision making under uncertainty. In the context of continuous programming techniques, its application has been made via parametric programming techniques, ranging, duality or quick reoptimization. Sensitivity analysis as a post-optimality analysis can start from the optimum solution of the program. It can be carried out on (i) objective function coefficients, (ii) right-hand side (resource availability), and (iii) the input-output (activity) matrix.

Sensitivity of the optimal solution vector and the optimal value of the objective function has been attempted by various writing including Saaty and Webb [1961] and Sengupta [1966] in both deterministic and stochastic models. In case of linear programming models, Saaty and Webb provided an operational measure of sensitivity coefficient K_{ij} by taking the partial derivatives of the optimal objective function Z(X) such that:

$$(1.5)\quad K_{ij} = -\frac{\delta Z}{\delta aij} = X_j\ Y_i$$

where X_j's are optimal primal variables and Y_i's are the optimal dual variables; $X_j \geq 0$; $Y_i \geq 0$; and a_{ij} is the objective function coefficient. These sensitivity indexes provide some idea as to how sensitive the objective function would be at a specific optimal point when the data variations are likely.

For considering implications, in the quadratic programming problem, of changes in the right-hand side vector the well-known procedures such as duality and parameterization are widely discussed in the literature. Boot [1964, p. 180] described a procedure for solution sensitivity to changes in an element of the linear part of the objective function:

$$(1.6) \quad Z(X) = A'X + X'BX$$

This method involves selecting an initial value of this element A_1 (say) and solving the problem for A_1. Assuming a non-degenerate solution set obtains, one can then express all Lagrangians explicitly in linear terms of A_1. Thus one can conceptually set $A_1 = 0$, obtain the first solution, then allow A_2 to change to its value in the problem, etc. This procedure is not very efficient, however.

This method can be modified similar to the Markowitz [1956] problem. The procedure premultiplies the first term on the right side of the objective function A (say $Z = AX - X'BX$) by a scalar λ. If the problem is well behaved (convex) then $\lambda = 0$ provides the solution $X = 0$, since any other non-negative X provides a non-positive objective function value. The value of λ is then permitted to increase until $\lambda = 1$ and the critical points are mapped.

Wolf [1959] provides yet another computational algorithm using a parametric formulation of the quadratic programming problem as the starting point. Sensitivity to uncertainty in the quadratic part of the objective function and the constraint matrix is somewhat more difficult but can follow similar procedures. For example, for persistent changes in the elements of the quadratic form matrix, care has to be taken not to change the negative semi-definiteness of the matrix. The effects of changes in an element of the constraint matrix are difficult to derive. Similarly to the previous algorithms, however, a parametric solution can be obtained by maximizing the objective function (1.6) subject to a constraint:

$$(1.7) \quad \rho CX \leq b.$$

For $\rho = 0$ there are no constraints; for $\rho = 1$ the original problem obtains. Thus ρ plays roughly the same role as λ in the case previously discussed.

There are a vast number of other parametric procedures, of course. While one method may prove highly efficient for one problem, it may prove quite costly for another formulation.

1.7 *Region Under Investigation.* The floodplain in Farmington, Connecticut was selected for the present investigation. It comprises almost 3,000 acres of which approximately 2,176 are undeveloped. Farmington is a growing community, as suggested by Table 1.1.

Farmington is within a 20-mile radius of the cities of Hartford, Bristol, New Britain, Waterbury and Torrington. It borders with two important populous and industrial complexes (Hartford and Bristol areas). Much of the industrial zoned land is accessible to railroads. Part of the industrial park is situated on the floodplain and the demand for industrial and other land uses remains strong in part due to the location of Route 4 and the proximity of the other public services. Despite the threats of floods, demand for urban development on these floodplains is rather strong. All these factors together with the availability of data on this floodplain and also the desire for land use planning by local officials, led to the selection of this area for analysis.

Table 1.1

Growth of Population in Farmington Town
(1930-1973)

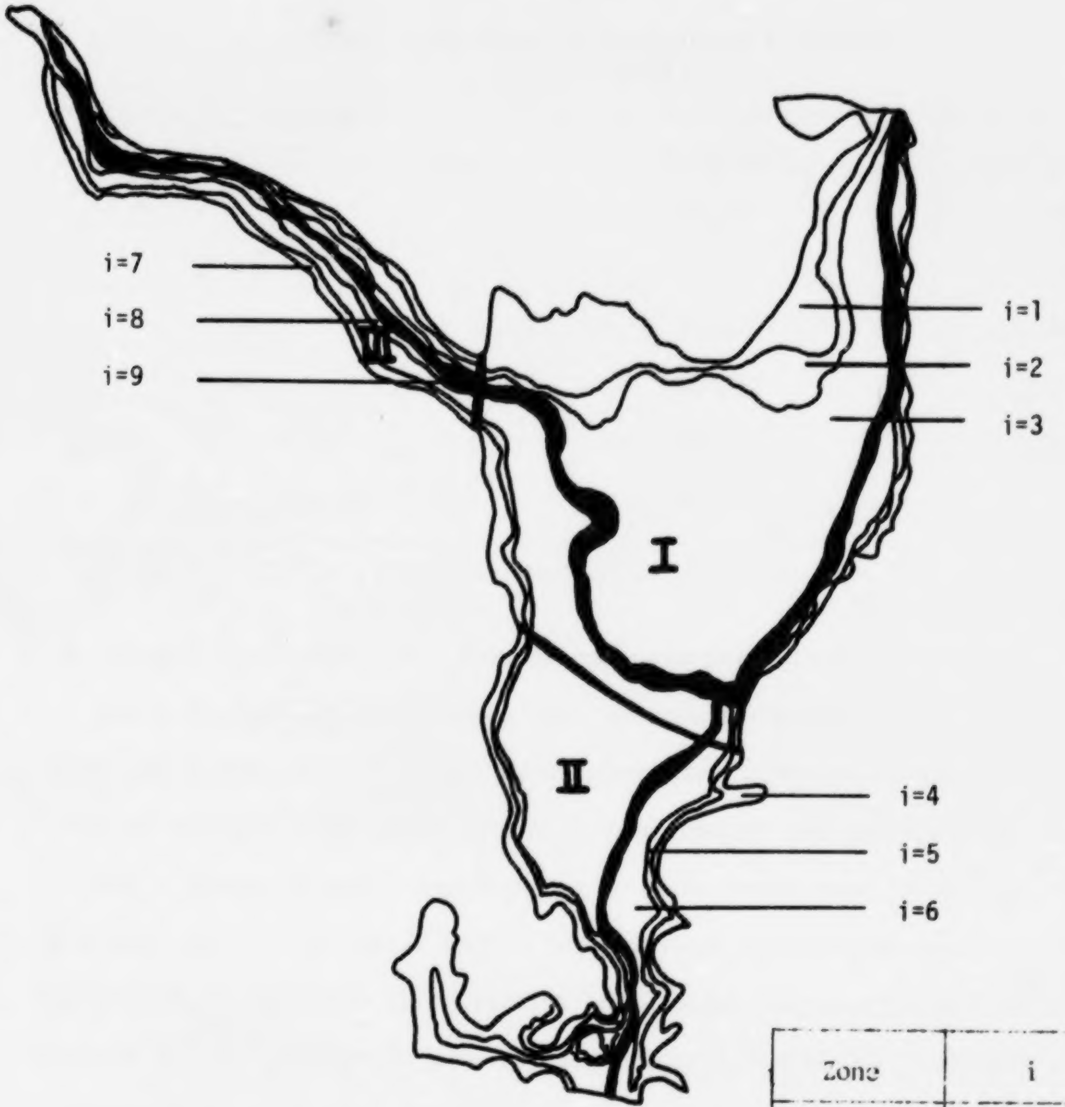
Year	Population	Percent Growth Over Previous Decade
1930	4,548	--
1940	5,313	16.82
1950	7,026	32.24
1960	10,813	53.89
1973	16,000	47.97
1980*	25,000	56.25

*Population for 1980 is projected by town planners.

The floodplain of Farmington was divided into three basic regions on the basis of the demand for various land uses. That is, each of these three regions is presumed homogeneous with respect to the demand for (and price of) land for the various uses. Each of these basic regions is further subdivided into three zones on the basis of flood frequency. These zones provide information regarding the probabilities of a flood occurring in a particular year and suggest the relative risk involved if development is permitted. The lowest frequency (risk) zone corresponds to the maximum flood of record (1955). The second zone reflects land which is expected to be flooded once every hundred years and the highest risk zone is the land which is flooded on an average every fifty years. These areas are shown in Figure 1.1 below.

Figure 1.1

Areal Designations for the Farmington Floodplain



Zone	i
500 Year	1, 4, 7
100 Year	2, 5, 8
50 Year	3, 6, 9

Key

2. General Framework

The objective of the model developed here is to identify the economically efficient combination of spatial-temporal land use activities, flood proofing decisions, and dam construction, given a specific set of community land use goals, expected growth, flood risk, and demand-supply conditions for land in various uses. The objective function uses the efficiency goal with economic rent as a measure of returns to land in various uses. This function also incorporates a measure of aversion to risk (uncertainty). Other goals such as expansion of population or industrial capability or environmental issues may also be legitimate community objectives. In the present approach, these are treated as constraints.

For this framework, the control variables (X_{ijt}) devote the portions of an area of floodplain and adjacent land (not necessarily contiguous) i to be assigned a particular use j in period t and beyond. Examples of uses j are: residential (single family homes and apartments), industrial, commercial, and open space. The designation of the land to be contained in a particular category i is conditional upon not only location within the floodplain with respect to flood risk but also upon the relevant factors which account for differences in the derived demand for such parcels.

Finally, as with Day's work, each variable (X_{ijt}) presumes some (optimal) level of flood proofing of structures as well as a given level of structural protection through dams, etc. Willis and Aklilu provide the methodology for determining the optimal level or amount of flood proofing for a given set of conditions (regarding probabilities of floods of various intensities and market values of structures) such that for any given ijt circumstance, there need be considered only one (dominant) level of flood proofing. Thus, the flood proofing decisions can be considered as separable. Similarly, each dam (or set of structural measures) in the presence of land use constraints, brings with it an associated benefit in terms of expected damage reductions as reflected by the differences in probability of various levels of flooding. These are reflected in the objective function below. Hence, each problem is solved for a particular dam specification, the expected costs of such an undertaking are subtracted from the respective objective function values and the final decisions are made by inspection.

This approach involving optimization with respect to structural measures outside the basic framework reduces the number of activities to the product of the numbers of areas, uses, and periods (ijt). For a two period horizon (each period representing an interval of five years duration) with nine regions and five uses (as in our test situation), there are then 90 activities.

2.1 *Constraints*. The decisions with respect to assignments (X_{ijt}) are constrained by a number of considerations, some of which will vary with the specifics of regional or community preferences and situations -- e.g., legal, political, institutional, and social considerations -- and some of which are basic to all regional applications. For example, an immediately evident set of restrictions is that for each area (i) and period (t), not more land than is available (P_i) should be developed. More formally,

$$(2.1) \quad \sum_{j,t} X_{ijt} \le P_i \qquad \forall_i$$

Second, to insure for each area that not more land is assigned to the j^{th} use in t than is available (and suitable), we can further require:

(2.2) $\sum_{t} X_{ijt} \le P_{ijt} \qquad \forall_{ijt}$

where P_{ijt} is acreage in i suitable for j and the t designation is redundant when the only factor which reduces acreage available over time is development. In the present regional situation, community planners wished to require, for example, that commercial development proceed at a rate no greater than fifteen acres per planning period.

Expressions (2.1) and (2.2), along with any other region-specific constraints (such as minimum levels of open space, maximum industrial concentrations, etc.), can be cast in general (matrix) form as:

(2.3) $CX \le P.$

While the dimensions of C for a typical situation may be fairly large for non-linear programming solution, as with Day's formulation, this matrix is quite sparse so that computer solution is generally rapid.

2.2 *Objective Function.* The objective function reflects, in part, land value per acre in alternative uses, where uses are defined sufficiently broadly to include flood proofing activities and to reflect results of other structural (dam) measures. Also, as previously indicated, the concept of economic rent is useful in this regard. With the same caveats Day clearly expresses, this rent concept is incorporated into the present objective function. Denoting expected economic rent by r_{ijt}, the measure can be considered as a set of constants for objective function purposes (as did Day for any period t). A more realistic presumption, however, is that r_{ijt} are functions of the decision variables. The quadratic programming approach below presumes the relationship between r_{ijt} and $\sum_{t'=1}^{t} X_{ijt'}$, is linear and continuous over the relevant range. Ignoring the stochastic residual for the moment, this translates to:

$$(2.4) \quad r_{ijt} = a_{ijt} + b_{jt} \sum_{t'=1}^{t} X_{ijt'}$$

where a_{ijt} and b_{jt} are parameters to be estimated. This representation, while less restrictive than Day's, is more restrictive than it needs to be. It was used in the test application in the interests of time and because it was considered to be a reasonable representation for this particular community. It presumes, of course, that rent slope is independent of region i and that demands (and rents) for a particular use in i are unrelated with demands (rents) for the same use in i', $i' \in I$, $i \neq i'$. It also presumes no interaction between land use activities -- another issue which Day found troublesome.

Each of these restrictions for the test situation can be lifted without complication in this quadratic programming approach. For example, the former restrictions (that rent slope is independent of i and rents for use j in i and i' are unrelated) can be lifted by including an i subscript on bjt and summing X over i as well. The latter restriction (that no interaction between land use activities exists) would require, for example, additional terms in (2.4) -- viz., for each r_{ijt}, rather than to recognize only a slope for j (bjt), there should be a similar term for each j, j = 1, ..., J. As an example, for a simple situation in which the three relevant uses (j = 1, 2, 3) were, respectively, residential, industrial, and open space, the latter restriction can be lifted by redefining (2.4) as:

$$(2.4)' \quad r_{ijt} = a_{ijt} + b_{1t} \sum_{t'=1}^{t} X_{i1t'} + b_{2t} \sum_{t'=1}^{t} X_{i2t} + b_{3t} \sum_{t'=1}^{t} X_{i3t'} \; .$$

For the residential rent structure, then b_{1t} expresses the effect of cumulative residential development, while b_{2t} and b_{3t} depict the partial effects of industrial development and open space preservation -- most likely negative and positive, respectively. Whether in any regional application this more general approach should be taken is, of course, an empirical question, the answer to which depends upon a judgment regarding the degree to which the more restrictive assumptions are valid for the region as well as data availability and cost. The important thing to note is that solution for the problem under either specification uses the same quadratic programming algorithm; only the procedures for estimation of the parameters would differ.

For the present formulation, the influence (for given j and t) of the investment in various structural measures on rent in region i is felt via the intercept (a_{ijt}). That is, the magnitude of r_{ijt} reflects in part expected flood damages (a function of type of structural measures taken) which, of course, vary across i and the costs of these measures. Expected economic rents, discounted to the present, for all X_{ijt} decisions over the planning horizon[8] can then be expressed compactly as:

$$(2.5) \quad Z = AX + X'BX,$$

where, A is $[a_{111} \; a_{211} \cdots a_{I11} \; a_{121} \cdots a_{IJ1} \; a_{112} \cdots a_{IJT}]$,

X is conformable, and the

IJT dimensional matrix B is given as:

---

[8] Economic rents of (2.4) for each period t are multiplied by $\sum_{t'=1}^{t} X_{ijt}$.

$$B = \begin{bmatrix} Q_{11} & Q_{12} & \cdots & Q_{1T} \\ Q_{12} & Q_{22} & & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & & \cdot \cdot \\ Q_{1T} & & \cdots & Q_{TT} \end{bmatrix}$$

where $Q_{tt'}$ is the IJ dimensional diagonal matrix defined as:

$$Q_{tt'} = \begin{bmatrix} q_{1tt'} & 0 & \cdots & 0 \\ 0 & q_{2tt'} & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot \\ \cdot & & & \cdot \cdot \\ 0 & \cdots & & q_{Jtt'} \end{bmatrix}$$

and $q_{jtt'}$ is the I dimensional scalar matrix of slopes given by $q_{jtt'} = \sum_{t=t}^{T} b_{jt} [\delta_I]$ for $t = t'$ and $q_{jtt'} = \sum_{t=t}^{T} b_{jt} [\delta_I]$ for $t \neq t'$, where $[\delta_I]$ is the I dimensional unit matrix.

As suggested earlier, major elements of uncertainty arise with respect to the estimation of the parameters of the economic rent function (2.5). Despite the emphasis in recent years on incorporating risk into decision frameworks -- e.g. Lin, *et. al.*, Scott and Baker, Barry and Robison, Chen and Baker, and Just -- empirical floodplain management frameworks continue in a deterministic mode, with "optimization" of some objective function couched only in terms of expected values. This seems surprising since the works cited above, based largely on the earlier efforts of Friedman and Savage, Markowitz, and Tobin, rather convincingly establishes the theoretical and empirical validity of risk aversion.

The approach commonly employed involves specifying the objective function as a quadratic form, equating risk with variance, including the variance-covariance matrix resulting from the estimation of the objective function parameters into the quadratic part of the objective function multiplied by a "risk aversion parameter" (scalar). This parameter can then be varied to establish the effect of risk and these solutions can be summarized in a mean-variance (E-V) context. Under this approach, the objective function for the floodplain management framework can be specified as:

(2.6) $Z^* = AX + X' (B - \phi\Omega)X$,

where, A, B, X are as previously defined

ϕ is the scalar risk aversion parameter, and

Ω is the covariance matrix for the economic rent estimations.

This approach both considers that risk aversion[9/] (concave utility functions) is the only relevant case and that variance can be used as the sole measure of risk.[10/] An aversion to risk would, therefore, imply an aversion to variance, with the implication (Markowitz's E-V criteria) that when the mean and variance are both higher in one distribution than another, one cannot choose between the two in terms of efficiency alone.

Hanoch and Levy, among others, show that this is invalid as is the usual E-V presumption that a larger mean and a smaller variance ought to be preferred by risk averse people. While Tobin claims the mean-variance criterion to be valid only for situations in which the utility function is quadratic and the distributions of the activities (portfolios) are members of a two-parameter

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[9/] Arrow and Yaari argue on both theoretical and empirical grounds that this is the case.

[10/] This has become common since the works of Tobin, Markowitz, Friedman and Savage, Baumol, Lintner, and Sharpe.

family, even the usefulness of these two cases has been subjected to criticism -- e.g., by Arrow, Hirshleifer, Pratt, and Rothschild and Stiglitz.

Tobin [1969] rather persuasively argues that definitions ought to be chosen for their usefulness as well as their consistency, however. Without debating whether the detractors have proven their cases, the mean-variance approach (and expression (2.6)) is adopted here as a useful construct with all attendant caveats.

3. Regional Application

Recall that the floodplain under investigation is divided into three regions on the basis of demand for various land use activities. Region One comprises all land east of the area under Connecticut Encroachment Laws and north of Meadow Road. Region Two includes all land south of Meadow Road and Region Three includes the Unionville area which has most of its flood prone land under the jurisdiction of Connecticut Encroachment Laws.

Demand for development in Region One is the greatest because of the present construction along Farmington Avenue. The industrial park is located in Region Two making demand for industrial development greatest, but because of the location of Shade Swamp Sanctuary the demand for other urban uses is lowest in this region.

Each of these three regions is further subdivided into three risk zones; namely, 50 year flood zone, 100 year flood zone, and 500 year flood zone. Five different land use activities are considered for the present analysis. These are as follows:

(i) Single Homes

(ii) Apartments

(iii) Industrial Use

(iv) Commercial Use

(v) Open Space

The test problem, then, considered nine regions, five uses (single family homes, apartments, industrial uses, commercial uses, and open space), and two planning periods. For the model, variations were explored with respect to risk aversion values (ϕ), potential dam configurations, discount rates assumed, and with respect to values of the damage coefficient for structures (Day uses an expected value of this coefficient as estimated by Sheaffer). The analysis has been carried out using three basic decision models. Model 1 considers land use planning without structural measures for reducing flood damages; Model 2 considers flood proofing decisions; and Model 3 takes into consideration the decision of building a dam or reservoir for protection from floods. In each model four different runs were made in order to test the sensitivity of the optimal planning decisions due to a change in discount rate and the flood damage coefficient (see Appendix B for these coefficients and Appendix A for the model data). The effect of uncertainty on the optimal planning decisions are studied and discussed. The models thus presented here are designed to generate policy alternatives and explore at the same time the implications of any given set of objectives.

For these formulations, no extra restraints other than population growth constraints and minimal industrial and commercial growth constraints were used. One could, as an alternative formulation, include a side condition that at least "d" acres of open space be set aside for each acre developed in each region. This was suggested by a local community leader as a realistic community objective. Such a situation did not arise in our case as the model without this side restriction provided land for open space and for other development in the ratio which varied from 2:1 to 3:1.

Results of these sets of formulations are set out in the tables which follow. To facilitate the discussion and comparison of the results of Model 1 and Model 2 the results are presented in the same table. The solutions with flood proofing decisions are provided in parentheses.

3.1 *Decision Model 1.* This model does not consider any structural damage reduction measure, but rather assumes the existing state of nature in this regard, and the planning of optimal land use is worked out in all the regions. Assuming 5 percent rate of discount and damage coefficient (a_h) equal to 0.052 (Table 3.1) the model suggested development of roughly 62 acres under single family homes in the 50 year flood zone in Region 1 and about 59 acres in the 500 year flood zone. The development of single family homes was suggested in Region 1 and Region 3 primarily. Apartment complexes were completely restricted from high risk zones in all the regions, obviously because of heavy expected damages due to floods. Industrial and commercial development is suggested in the 500 year flood zones. The model developed roughly 16 acres in Region 1 and 23 acres in Region 3 for industrial use and 15 acres of land for commercial use. Most of it was in Region 1. An additional 15 acres were allocated to commercial development in period 2 but this development was spread over Regions 1 and 3, thus developing roughly 6 acres in Region 1 and 9 acres in Region 3. In period 2, 42 acres would be developed under single homes in Region 1 (high risk zone), 11 acres in Region 2 and 17.56 acres in Region 3. All of this was allocated in high risk zones. In Region 1, 19 acres were suggested to be developed for apartment complexes in low risk zones. All open space development showed

Table 3.1

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion (ϕ) = 0.0*

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	62.38 (152.85)	-- (8.57)	59.54 (2.58)	42.08 --	-- --	-- --
	2	-- (125.46)	39.12 --	92.03 --	-- (42.54)	5.88 --	19.02 --
	3	-- --	-- --	15.87 --	-- (27.30)	-- --	-- --
	4	-- (15.00)	-- --	14.13 --	-- (15.00)	-- --	6.41 --
	5	1057.54 (783.85)	-- (36.43)	-- (204.42)	-- --	-- --	-- --
2	1	-- (73.00)	4.00 --	-- --	11.30 --	-- --	-- --
	2	-- (20.00)	2.00 --	18.00 --	-- --	-- --	-- --
	3	-- (16.10)	-- --	-- --	-- (27.70)	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	458.70 (333.20)	-- (6.00)	-- (18.00)	-- --	-- --	-- --
3	1	-- --	101.63 (25.77)	7.81 (2.69)	17.56 --	-- (54.86)	-- (43.69)
	2	-- (41.10)	6.37 --	39.63 --	-- --	-- (4.90)	-- --
	3	-- (38.90)	-- --	23.09 --	-- --	-- --	-- --
	4	-- --	-- --	.88 --	-- --	-- --	-- --
	5	268.00 (214.98)	-- --	-- --	-- --	-- (19.40)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

up in high risk zones in all the regions. About 1,057 acres were allocated to open space in Region 1, 459 in Region 2, and 268 in Region 3. For every acre developed under various uses, there were about 3 acres of open space. This allocation was suggested without restricting open space development in the model as suggested earlier.

There was not a striking difference in the allocation of land to various activities when the discount rate was raised to 10 percent (Table 3.3). However, when the damage coefficient (a_h) was changed to .057, the allocation of land to single family homes in high risk zones increased by about 40 percent over the previous allocation (Table 3.2). About 69 acres were allocated for single homes in the high risk zone of Region 2, of which 23 acres were suggested to be developed in time period 2. A total of 55 acres of industrial development resulted in the high risk zone of Region 2 in period 1, and 40.87 acres in low risk zone of Region 3 in period 2. Altering the assumed damage coefficient did not allow any development in Region 2 for industrial use, in spite of the fact that the demand for land for industrial use in this region is the greatest because of the location of the industrial park in this region. The difference in the two situations, however, was not reflected in the allocation of land to various uses but rather in their temporal allocation. A substantial amount of land is available for development in period 2 when the damage coefficient was increased. For example, in the low risk zone of Region 1, 111 acres were allocated for apartment complexes, of which 19 acres called for development in period 2. But when the damage coefficient was raised to .057, 62.34 of 122 acres allocated for apartment complexes were suggested in period 2. Industrial use was sensitive to the assumptions regarding the proper damage coefficient.

Table 3.2

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion (ϕ) = 0.0*

		Planning Period					
		1			2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	108.09	--	55.91	--	--	--
		(106.96)	(12.59)	(44.45)	--	--	--
	2	--	34.13	60.66	--	10.87	62.34
		(51.70)	(19.50)	(14.67)	(43.12)	(12.91)	(26.10)
	3	--	--	--	--	--	14.13
		--	--	--	(23.69)	--	--
	4	--	--	13.96	--	--	--
		(11.67)	--	--	(8.67)	--	--
	5	1053.91	--	--	--	--	--
		(916.19)	--	(121.77)	--	--	--
2	1	45.62	4.00	--	23.00	--	--
		(52.67)	(6.00)	(14.33)	--	--	--
	2	--	2.00	18.00	--	--	--
		(20.00)	--	--	--	--	--
	3	55.00	--	--	--	--	--
		(1.86)	--	--	(28.18)	--	--
	4	--	--	--	--	--	--
		--	--	--	--	--	--
	5	346.00	--	--	--	--	--
		(367.29)	--	(3.67)	--	--	--
3	1	39.95	80.33	4.75	1.96	--	--
		--	(70.68)	(56.32)	--	--	--
	2	--	19.75	26.25	--	--	--
		(20.41)	(18.31)	(7.29)	--	--	--
	3	--	--	--	--	--	40.87
		(53.14)	--	--	(3.13)	--	--
	4	--	--	1.04	--	7.92	7.08
		(3.33)	--	--	--	(6.33)	--
	5	268.00	--	--	--	--	--
		(238.93)	--	(16.40)	--	(12.68)	--

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.3

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion (ϕ) = 0.0*

		Planning Period					
			1		2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	45.08 (151.59)	5.53 (1.51)	65.92 --	47.47 (10.90)	-- --	-- --
	2	-- (136.39)	35.27 --	93.43 --	-- (31.61)	4.20 --	16.46 --
	3	-- --	-- --	9.82 --	-- (28.23)	-- --	-- --
	4	-- (15.00)	-- --	14.17 --	-- (15.00)	-- --	7.20 --
	5	1069.44 --	-- (43.49)	-- (207.00)	-- --	-- --	-- --
2	1	-- (71.43)	4.00 --	-- --	-- (1.57)	-- --	-- --
	2	-- (20.00)	2.00 --	18.00 --	-- --	-- --	-- --
	3	-- (19.37)	-- --	-- --	-- (26.77)	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	470.00 (330.85)	-- (6.00)	--- (18.00)	-- --	-- --	-- --
3	1	-- --	105.47 (.58)	16.32 --	5.21 --	-- (81.84)	-- (44.58)
	2	-- (44.37)	2.53 --	43.47 --	-- --	-- (1.62)	-- --
	3	-- (35.62)	-- --	11.57 --	-- --	-- --	-- --
	4	-- --	-- --	0.83 --	-- --	-- --	7.80 --
	5	268.00 (214.12)	-- --	-- (35.42)	-- --	-- (18.45)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

With a change in damage coefficient from .052 to .057 the land allocated for the industrial development reached the maximum limit put on its use in both the time periods, whereas a damage coefficient of .052 allowed development of about 39 acres only in period 1 and that too in low risk zones only. Raising the damage coefficient brought in more land under single family homes. For the case where the rate of discount was raised to 10 percent and the damage coefficient was also raised to .057, industrial development in high risk zones was eliminated and was shifted to low risk zones of Region 1 and Region 3.

3.2 *Decision Model 2.* Assuming a discount rate of 5 percent and a damage coefficient a_h = .052 this model suggests allocation of land under apartment complexes in high risk zones which was completely prohibited without flood proofing of structures. Allocation of land for single family homes increased considerably. Development in high risk zones turned out to be relatively more profitable. For instance, industrial development showed up in high risk zones in all the regions. Similarly, commercial development was also suggested in high risk zones. One striking feature of this model was regarding allocation of land to open space. The total land allocated to open space in the floodplain was nearly the same in both models. In Model 1, land for open space was concentrated in high risk zones in all the regions. But for Model 2, where flood proofing was considered, the distribution of this land for open space was different. Model 2 allocates the land for open space in all risk zones in all regions. Period 2 calls for development of an additional 28 acres of land in single family homes and 23 acres of land in apartment complexes. Industrial development in period 1 was confined to Region 2 and 3 but in period 2 development was suggested in Region 1 and 2.

As also observed in Model 1, the solutions were not sensitive to the change in the rate of discount assumed in this model. For example, when the rate of interest was raised to 10 percent (leaving the damage coefficient unchanged), no significant change in the solution was observed (Table 3.4). An increase in the damage coefficient, a_h, from .052 to .057 reduced the allocation of land to single family homes and apartment complexes and increased the open space allocation considerably in high risk zones because the damages would outweigh the benefits of development in high risk zones. Also, it allowed less land to be developed in period 2. In both of these models, it was observed that the solution vectors were sensitive to the change in damage coefficient. But in the case of the discount rate, the change in the solution vector was not spectacular, at least in the range considered in the present study.

3.3 *Decision Model 3.* This model includes the decision of building dams or reservoirs for flood control purposes.[11/] The results of this model are presented in Tables 3.5 and 3.6. Assuming a 5 percent rate of discount and a damage coefficient $a_h = .052$, the model develops roughly 130 acres under single homes and about 107 acres under apartment complexes in the high risk zone of Region 1. It further suggests development of another 55 acres under apartment complexes in period 2 in the high risk zone. No development of single homes was suggested in the high risk zone of Region 3, although roughly 126 acres of land were developed under single homes in the other

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[11/] For details of how dams are incorporated into the decision model, refer to Appendix E.

Table 3.4

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion (ϕ) = 0.0*

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	125.79 --	-- (16.30)	28.63 (43.22)	9.58 (104.49)	-- --	-- --
	2	-- (76.06)	39.49 (26.98)	68.57 (19.61)	-- (30.13)	5.51 (1.72)	54.43 (13.50)
	3	-- --	-- --	25.50 --	-- (24.07)	-- --	16.27 --
	4	-- (13.90)	-- --	13.61 --	-- (11.95)	-- --	-- --
	5	1026.63 (901.41)	-- --	-- (130.67)	-- --	-- --	-- --
2	1	44.01 (57.17)	-- --	-- --	28.99 --	-- --	-- --
	2	-- (20.00)	6.00 (6.00)	14.00 (9.83)	-- --	-- --	-- --
	3	-- (.40)	-- --	4.00 --	-- (30.93)	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	397.00 (361.50)	-- --	-- (8.17)	-- --	-- --	-- --
3	1	34.30 --	70.01 (71.55)	-- (55.45)	22.70 --	-- --	-- --
	2	-- (24.30)	25.02 (18.24)	20.36 (3.46)	-- --	0.62 --	-- --
	3	-- (54.60)	-- --	25.50 --	-- --	-- --	30.09 --
	4	-- (1.10)	-- --	1.40 --	-- --	12.35 (3.05)	2.65 --
	5	268.00 (231.75)	-- --	-- (21.09)	-- --	-- (15.16)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.5

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rate, Damage Coefficient (a_h) of 0.052 and 0.057*, and Risk Aversion (ϕ) = 0.0

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	130.47 (134.56)	17.57 (16.16)	15.97 (13.28)	-- --	-- --	-- --
	2	106.87 (131.67)	-- --	-- --	55.35 (36.33)	5.78 --	-- --
	3	-- --	-- --	-- --	20.40 (22.14)	-- --	-- --
	4	15.00 (15.00)	-- --	-- --	15.00 (15.00)	-- --	-- --
	5	818.91 (807.29)	21.66 (28.84)	191.03 (193.72)	-- --	-- --	-- --
2	1	73.00 (73.00)	-- --	-- --	-- --	-- --	-- --
	2	20.00 --	-- --	-- --	-- (20.00)	-- --	-- --
	3	-- (4.48)	-- --	-- --	34.60 (32.85)	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	342.40 (339.67)	6.00 (6.00)	18.00 (18.00)	-- --	-- --	-- --
3	1	-- --	76.76 (50.67)	50.24 (50.00)	-- --	-- --	-- --
	2	25.00 (29.48)	-- --	-- --	-- --	21.00 (16.52)	-- --
	3	55.00 (50.52)	-- --	-- --	-- --	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	228.00 (223.52)	-- --	29.76 (30.01)	-- --	10.24 (14.47)	-- --

*Numbers in parentheses indicate land use decisions assuming damage coefficient to be .057.

Table 3.6

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rate, Damage Coefficient (a_h) of 0.052 and 0.057*, and Risk Aversion (ϕ) = 0.0

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	111.10 (114.11)	18.95 (18.47)	33.94 (31.43)	-- --	-- --	-- --
	2	79.58 (83.54)	9.93 (9.93)	-- --	39.70 (39.07)	16.12 (16.61)	22.68 (18.85)
	3	20.53 --	-- --	-- --	2.52 (37.93)	-- --	-- --
	4	13.66 (15.00)	-- --	-- --	15.00 (15.00)	-- --	-- --
	5	879.91 (857.35)	-- --	150.38 (156.72)	-- --	-- --	-- --
2	1	57.26 (65.28)	6.00 (6.00)	9.74 (1.72)	-- --	-- --	-- --
	2	20.00 (20.00)	-- --	-- --	-- --	-- --	-- --
	3	34.46 --	-- --	-- --	-- (17.07)	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	358.28 (367.72)	-- --	8.26 (16.28)	-- --	-- --	-- --
3	1	-- --	72.82 (73.18)	54.18 (53.82)	-- --	-- --	-- --
	2	26.76 (24.93)	15.60 (13.47)	-- --	-- --	3.63 (7.60)	-- --
	3	-- (55.00)	-- --	-- --	52.48 --	-- --	-- --
	4	.76 --	.59 --	-- --	-- --	-- --	-- --
	5	226.82 (228.07)	-- --	25.82 (26.18)	-- --	15.35 (13.75)	-- --

*Numbers in parentheses indicate land use decisions assuming damage coefficient to be .057.

two risk zones in Region 3. Industrial development is suggested in Region 3 in period 1 and in Region 1 and 2 in period 2. All commercial development is suggested in Region 1 for both planning periods. Without restricting the development of open space the model suggested a ratio of 2.25 acres of open space to every acre developed under other categories.

This model does not show any appreciable sensitivity to the damage coefficient in the range .057 to .052. The only notable change that was in Region 2 where the 20 acres of land allocated for apartment complexes are shifted from period 1 to period 2 (Table 3.5). Similarly, with the 10 percent rate of discount no change was found in the optimal solution when the damage coefficient was changed from .052 to .057 (Table 3.6). However, some degree of sensitivity was noticed in response to the change in rate of discount. When this rate was raised to 10 percent from 5 percent and assuming a damage coefficient of .052, about 111.0 acres of land were allocated to single homes as compared to 130 in the high risk zone of Region 1. More land was developed in low risk zones of all the regions. The land for industrial development was now allocated to Region 1 and 2 in period 1 and this development for period 2 was suggested in Region 3. Commercial development was restricted to Region 1 in high risk zones in both the planning periods. This model was found to be insensitive to the damage coefficient but sensitive to the rate of discount. The dams reduce the frequency of flooding in the various zones, thereby considerably reducing the risk associated with each zone. The amount of change in the damage coefficient (as considered in this study) obviously did not have a striking influence on reduction of damages as compared to the influence of changes in the discount rate (to which the optimal solution was sensitive). The sensitivity of optimal land use decisions could also be observed by glancing through the expected values of the objective function (Tables 3.22 through 3.24). The objective function value is reduced considerably when the rate of discount is changed. But the change due to the damage coefficient is negligible by comparison.

3.4 *Effects of Uncertainty on the Optimal Decisions.* In the previous discussions, the decision-maker was assumed to have completely ignored the uncertainties associated with the planning of land use on floodplains. The decisions were made as if the outcomes were certain. In the present discussion we introduce the element of uncertainty into our model. The demand (rent) function (2.4) has now been respecified by recognizing the stochastic nature of the price/rent quantity relationship. With the help of unit normal deviates a variance covariance matrix (Ω) of Z^* in (2.6) was built.[12] The results of this formulation where the uncertainty component enters directly into the objective function are presented in Tables 3.7 through 3.16. This decision model takes into account the risk averse (ϕ) behavior of the individuals occupying the floodplain. Various levels of risk aversion were considered in the analysis, but our discussion below is restricted to the model where $\phi = .01$ (for the previous results), of course, $\phi = 0.0$ is implicit).

3.4.1 *Decision Model 1.* Assuming the rate of discount to be 5 percent and damage coefficient $a_h = .052$ and risk aversion $\phi = .01$, no striking change was noticed in the allocation of land to various uses in all the 9 regions. About 30 acres of additional land were suggested for development in periods 1 and 2. The pattern of development did not change. Also, the

Table 3.7

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion (ϕ) = 0.01*

		Planning Period					
		1			2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	62.97 (152.67)	2.93 (8.65)	50.23 (2.67)	47.87 --	-- --	-- --
	2	-- (124.82)	39.71 --	92.62 --	-- (43.18)	2.36 --	9.25 --
	3	-- --	-- --	26.68 --	-- (41.75)	-- --	-- --
	4	-- (15.00)	-- --	14.19 --	-- (5.57)	-- --	14.03 --
	5	1051.87 (779.01)	-- (36.35)	-- (204.33)	-- --	-- --	-- --
2	1	-- (73.00)	3.03 --	-- --	37.49 --	-- --	-- --
	2	-- (20.00)	2.98 --	17.03 --	-- --	-- --	-- --
	3	-- (17.20)	-- --	-- --	-- (13.25)	-- --	-- --
	4	-- --	-- --	-- --	-- (9.43)	-- --	.98 --
	5	432.51 (337.13)	-- (6.00)	-- (18.00)	-- --	-- --	-- (33.63)
3	1	-- --	102.07 (25.12)	10.80 (2.05)	14.13 --	-- (55.50)	-- (44.33)
	2	-- (42.20)	5.93 --	40.07 --	-- --	-- (3.80)	-- --
	3	-- (37.80)	-- --	28.32 --	-- --	-- --	-- --
	4	-- --	-- --	.81 --	-- --	-- --	-- --
	5	218.00 (214.98)	-- --	-- (33.62)	-- --	-- (19.39)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.8

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion (ϕ) = 0.01*

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	116.80 (106.58)	-- (12.59)	47.20 (44.82)	-- --	-- --	-- --
	2	-- (51.69)	34.06 (19.50)	60.59 (14.68)	-- (42.98)	10.94 (12.91)	62.41 (26.24)
	3	-- --	-- --	-- --	-- (37.18)	-- --	13.84 --
	4	-- (15.00)	-- --	14.06 --	-- (6.15)	-- --	9.89 --
	5	1045.20 (902.41)	-- --	-- (121.26)	-- --	-- --	-- --
2	1	45.54 (52.78)	2.51 (6.00)	-- (14.21)	24.93 --	-- --	-- --
	2	-- (20.00)	3.48 --	16.51 --	-- --	-- --	-- --
	3	55.00 (1.90)	-- --	-- --	-- (15.02)	-- --	-- --
	4	-- --	-- --	-- --	-- (8.85)	-- --	1.48 --
	5	344.51 (371.43)	-- --	-- (3.78)	-- --	-- --	-- --
3	1	31.71 --	85.52 (70.82)	9.76 (56.17)	-- --	-- --	-- --
	2	-- (24.11)	19.77 (16.50)	26.22 (5.38)	-- --	-- --	-- --
	3	-- (53.09)	-- --	-- --	-- (2.79)	-- --	41.15 --
	4	-- --	-- --	.94 --	-- --	2.70 --	1.92 --
	5	268.00 (228.89)	-- --	-- (18.44)	-- --	-- (20.66)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.9

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion (ϕ) = 0.01*

		Planning Period					
		1			2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	47.94 (151.14)	9.31 (1.62)	52.44 --	54.30 (11.23)	-- --	-- --
	2	-- (135.93)	35.68 --	96.27 --	-- (32.06)	-- --	2.92 --
	3	-- --	-- --	25.88 --	-- (42.61)	-- --	-- --
	4	-- (15.00)	-- --	15.00 --	-- (5.50)	-- --	14.47 --
	5	1059.75 (768.50)	-- (43.37)	-- (207.00)	-- --	-- --	-- --
2	1	-- (70.97)	3.47 --	-- --	22.29 (2.02)	-- --	-- --
	2	-- (20.00)	2.52 --	17.47 --	-- --	-- --	-- --
	3	-- (20.26)	-- --	-- --	-- (12.38)	-- --	-- --
	4	-- --	-- --	-- --	-- (9.50)	-- --	.52 --
	5	447.70 (334.85)	-- (6.00)	-- (18.00)	-- --	-- --	-- --
3	1	-- --	105.22 (.13)	14.66 --	7.10 --	-- (82.29)	-- (44.57)
	2	-- (45.26)	2.77 --	43.22 --	-- --	-- (.73)	-- --
	3	-- (34.73)	-- --	22.10 --	-- --	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	268.00 (214.12)	-- --	-- (35.42)	-- --	-- (18.45)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.10

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion $(\phi) = 0.01$*

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	125.79 --	-- (16.30)	21.94 (43.47)	16.27 (104.23)	-- --	-- --
	2	-- (76.03)	39.49 (26.95)	68.56 (19.58)	-- (30.06)	5.51 (1.75)	46.18 (13.63)
	3	-- --	-- --	26.83 --	-- (38.33)	-- --	22.33 --
	4	-- (15.00)	-- --	15.00 --	-- (6.13)	-- --	6.16 --
	5	1019.94 (892.22)	-- --	-- (130.32)	-- --	-- --	-- --
2	1	44.01 (57.26)	-- (6.00)	-- (9.73)	28.99 --	-- --	-- --
	2	-- (20.00)	5.96 --	14.04 --	-- --	-- --	-- --
	3	-- (2.12)	-- --	1.34 --	-- (16.67)	-- --	-- --
	4	-- --	-- --	-- --	-- (8.87)	.04 --	2.62 --
	5	397.00 (365.07)	-- --	-- (8.26)	-- --	-- --	-- --
3	1	34.29 --	76.32 (71.62)	-- (55.38)	16.39 --	-- --	-- --
	2	-- (27.12)	25.02 (16.85)	20.50 (20.03)	-- --	.48 --	-- --
	3	-- (52.88)	-- --	26.82 --	-- --	-- --	32.67 --
	4	-- --	-- --	-- --	-- --	6.19 --	-- --
	5	268.00 (225.88)	-- --	-- (22.59)	-- --	-- (19.53)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.11

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion $(\phi) = 0.02$*

		Planning Period					
		1			2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	63.59 (147.03)	10.65 (11.48)	59.58 (5.49)	30.18 --	-- --	-- --
	2	-- (125.02)	34.35 --	93.24 --	-- (42.98)	-- --	.94 --
	3	-- --	-- --	27.51 --	-- (41.08)	-- --	.24 --
	4	-- (15.00)	-- --	15.00 --	-- --	-- --	10.50 --
	5	773.30 (624.85)	-- (33.52)	-- (201.51)	-- --	-- --	-- --
2	1	-- (73.00)	-- --	-- --	58.33 --	-- --	-- --
	2	-- (20.00)	4.59 --	14.90 --	-- --	-- --	-- --
	3	-- (16.86)	-- --	-- --	-- (13.92)	-- --	-- --
	4	-- --	-- --	-- --	-- (15.00)	1.41 --	3.10 --
	5	386.05 (331.22)	-- (6.00)	-- (18.00)	-- --	-- --	-- --
3	1	-- --	102.10 (25.32)	11.00 (2.24)	13.89 --	-- (55.31)	-- (44.13)
	2	-- (41.86)	5.90 --	40.10 --	-- --	-- (4.14)	-- --
	3	-- (38.14)	-- --	27.49 --	-- --	-- --	1.41 --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	268.00 (214.98)	-- --	-- (33.63)	-- --	-- (19.40)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.12

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion (ϕ) = 0.02*

Region i	Land Use Activity j	Planning Period 1: 50 Year Flood Zone	Planning Period 1: 100 Year Flood Zone	Planning Period 1: 500 Year Flood Zone	Planning Period 2: 50 Year Flood Zone	Planning Period 2: 100 Year Flood Zone	Planning Period 2: 500 Year Flood Zone
1	1	112.55 (101.37)	-- (12.59)	51.45 (50.04)	-- --	-- --	-- --
	2	-- (51.70)	34.63 (19.50)	61.15 (14.68)	-- (40.97)	10.38 (12.91)	59.34 (28.25)
	3	-- --	-- --	-- --	-- (33.62)	-- --	10.88 --
	4	-- (15.00)	-- --	14.20 --	-- --	-- --	9.98 --
	5	754.98 (708.54)	-- --	-- (114.03)	-- --	-- --	-- --
2	1	46.11 (52.52)	-- (6.00)	-- (14.48)	26.89 --	-- --	-- --
	2	-- (20.00)	5.21 --	14.35 --	-- --	.44 --	-- --
	3	55.00 (1.97)	-- --	-- --	-- (19.05)	-- --	-- --
	4	-- --	-- --	-- --	-- (15.00)	.35 --	3.65 --
	5	342.00 (361.46)	-- --	-- (3.52)	-- --	-- --	-- --
3	1	30.98 --	86.89 (70.83)	9.19 (56.17)	-- --	-- --	-- --
	2	-- (24.65)	20.11 (16.24)	25.89 (5.12)	-- --	-- --	-- --
	3	-- (53.03)	-- --	-- --	-- (2.32)	-- --	44.12 --
	4	-- --	-- --	.80 --	-- --	1.02 --	-- --
	5	268.00 (228.35)	-- --	-- (18.71)	-- --	-- (20.94)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.13

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.052 and Risk Aversion (ϕ) = 0.02*

Region i	Land Use Activity j	Planning Period 1: 50 Year Flood Zone	Planning Period 1: 100 Year Flood Zone	Planning Period 1: 500 Year Flood Zone	Planning Period 2: 50 Year Flood Zone	Planning Period 2: 100 Year Flood Zone	Planning Period 2: 500 Year Flood Zone
1	1	72.58 (150.59)	16.25 (5.91)	60.65 --	14.53 (7.50)	-- --	-- --
	2	-- (135.38)	28.75 --	92.45 --	-- (32.62)	-- --	-- --
	3	-- --	-- --	28.31 --	-- (42.16)	-- --	-- --
	4	-- (15.00)	-- --	15.00 --	-- --	-- --	10.59 --
	5	773.87 (616.96)	-- (39.09)	-- (207.00)	-- --	-- --	-- --
2	1	-- (70.43)	-- --	-- --	43.67 (2.58)	-- --	-- --
	2	-- (20.00)	4.48 --	15.11 --	-- --	-- --	-- --
	3	-- (19.74)	-- --	-- --	-- (12.84)	-- --	-- --
	4	-- --	-- --	-- --	-- (15.00)	1.52 --	2.89 --
	5	388.89 (329.41)	-- (6.00)	-- (18.00)	-- --	-- --	-- --
3	1	-- --	104.63 --	10.68 --	.52 --	-- (82.43)	-- (44.58)
	2	-- (44.74)	3.37 --	42.63 --	-- --	-- (1.26)	-- --
	3	-- (35.26)	-- --	26.64 --	-- --	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	268.00 (214.12)	-- --	-- (35.42)	-- --	-- (18.45)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.14

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rates, Damage Coefficient (a_h) of 0.057 and Risk Aversion (ϕ) = 0.02*

		Planning Period					
		1			2		
Region i	Land Use Activity j	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	124.41 --	-- (16.34)	33.48 (48.77)	6.11 (98.88)	-- --	-- --
	2	-- (75.40)	38.11 (26.33)	67.20 (18.95)	-- (28.74)	6.89 (2.34)	35.78 (16.25)
	3	-- --	-- --	27.52 --	-- (34.95)	-- --	22.50 --
	4	-- (15.00)	-- --	15.00 --	-- --	-- --	-- --
	5	783.06 (702.13)	-- --	-- (123.03)	-- --	-- --	-- --
2	1	42.63 (57.00)	-- (6.00)	-- (10.00)	30.37 --	-- --	-- --
	2	-- (20.00)	5.56 --	14.44 --	-- --	-- --	-- --
	3	-- (2.46)	-- --	-- --	-- (20.05)	-- --	-- --
	4	-- --	-- --	-- --	5.53 (15.00)	5.47 --	.44 --
	5	389.03 (355.48)	-- --	-- (8.00)	-- --	-- --	-- --
3	1	32.91 --	82.02 (71.62)	-- (55.38)	12.07 --	-- --	-- --
	2	-- (27.46)	23.64 (16.68)	20.02 (1.86)	-- --	2.34 --	-- --
	3	-- (52.54)	-- --	27.48 --	-- --	-- --	32.50 --
	4	-- --	-- --	-- --	3.56 --	-- --	-- --
	5	268.50 (225.54)	-- --	-- (22.76)	-- --	-- (19.70)	-- --

*Numbers in parentheses indicate decisions assuming flood proofing of structures and contents.

Table 3.15

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 5 Percent Discount Rate, Damage Coefficient (a_h) of 0.052 and 0.057*, and Risk Aversion (ϕ) = 0.01

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	130.30 (134.36)	17.65 (16.26)	16.05 (13.38)	-- --	-- --	-- --
	2	106.87 (130.35)	-- --	-- --	55.30 (37.65)	5.83 --	-- --
	3	-- --	-- --	-- --	34.50 (37.09)	-- --	-- --
	4	15.00 (15.00)	-- --	-- --	5.62 (5.59)	-- --	-- --
	5	814.40 (801.95)	21.53 (28.74)	190.95 (193.62)	-- --	-- --	-- --
2	1	73.00 (73.00)	-- --	-- --	-- --	-- --	-- --
	2	20.00 --	-- --	-- --	-- (20.00)	-- --	-- --
	3	-- (6.29)	-- --	-- --	20.50 (17.91)	-- --	-- --
	4	-- --	-- --	-- --	9.38 9.41	-- --	-- --
	5	347.12 (343.40)	6.00 (6.00)	18.00 (18.00)	-- --	-- --	-- --
3	1	-- --	76.76 (49.35)	50.24 (49.89)	-- --	-- (27.76)	-- --
	2	25.00 (31.29)	-- --	-- --	-- --	21.00 (14.71)	-- --
	3	55.00 (48.71)	-- --	-- --	-- --	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	228.00 (221.71)	-- --	29.76 (30.11)	-- --	10.24 (16.18)	-- --

*Numbers in parentheses indicate land use decisions assuming damage coefficient to be .057.

Table 3.16

Land Use Management Decisions (Acres Zoned) by Region, Use, and Period, Assuming 10 Percent Discount Rate, Damage Coefficient (a_h) of 0.052 and 0.057*, and Risk Aversion (ϕ) = 0.01

Region i	Land Use Activity j	Planning Period					
		1			2		
		50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone	50 Year Flood Zone	100 Year Flood Zone	500 Year Flood Zone
1	1	110.95 (114.05)	18.95 (18.47)	34.10 (31.48)	-- ---	-- --	-- --
	2	78.78 (83.52)	9.13 (9.90)	-- --	40.44 (39.07)	16.91 (16.63)	22.74 (18.87)
	3	32.46 --	-- --	-- --	4.16 (49.50)	-- --	-- --
	4	15.00 (15.00)	-- --	-- --	6.07 (5.46)	-- --	-- --
	5	874.15 (885.40)	150.16 --	361.19 (156.64)	-- --	-- --	-- --
2	1	57.34 (65.33)	6.00 (6.00)	9.66 (1.67)	-- --	-- --	-- --
	2	20.00 (20.00)	-- --	-- --	-- --	-- --	-- --
	3	22.54 --	-- --	-- --	-- (5.50)	-- --	-- --
	4	-- --	-- --	-- --	8.93 (9.54)	-- --	-- --
	5	-- (369.63)	-- --	8.34 (16.32)	-- --	-- --	-- --
3	1	-- --	72.89 (73.18)	54.11 (53.82)	-- --	-- --	-- --
	2	29.16 (25.00)	14.81 (13.45)	-- --	-- --	2.04 (7.55)	-- --
	3	-- (55.00)	-- --	-- --	50.84 --	-- --	-- --
	4	-- --	-- --	-- --	-- --	-- --	-- --
	5	223.84 (228.00)	-- --	25.89 (20.18)	-- --	18.26 (13.82)	-- --

*Numbers in parentheses indicate land use decisions assuming damage coefficient to be .057.

expected economic rent from the two situations did not vary much. In fact, there was no striking difference in all these situations when compared to its counterpart where risk aversion ϕ was assumed to be zero. The differences did show up when ϕ was assumed to take a value beyond .02. Some of the available land was not utilized. These decisions are further analyzed in the next section, where the trade-off between the expected net returns and the variance associated with it are analyzed.

3.4.2 *Decision Model 2.* With flood proofing decisions the optimal land use policies in the situations where ϕ ranged from $\lambda = 0.0$ to $\lambda = 0.01$ did not exhibit any remarkable change. In both models and in all situations, the maximum land suggested to be developed under various uses other than open space was the maximum available, 738 acres. Sensitivity to interest rate was not notable, but some sensitivity with respect to the damage coefficient was apparent. Up to the level when $\phi = 0.02$, there was no solution sensitivity except that open space started yielding negative marginal returns beyond certain allocated acreages thereby suggesting lower and lower allocation to open space. The ratio of open space land to development under other uses varied between 2 and 3. These results are tabulated in Tables 3.17 through 3.21.

3.4.3 *Decision Model 3.* With the decision to incorporate dams for reduction of the flood losses to floodplain occupants and with assumption of risk aversion behavior of individuals occupying the plains, optimal land use policies did not change when risk aversion (ϕ) = .01 compared to when it is assumed to be 0.0. The only change observed was in the temporal allocation of land for commercial development. Assuming risk aversion to be zero, the commercial development for both periods was suggested in Region 1. But when

Table 3.17

Allocation of Land to Various Uses by Period of Development and the Ratio of Open Space to Other Development for Risk Aversion $\phi = 0.0$

		Discount Rate							
		.05				.10			
		Damage Coefficient							
		.052		.057		.052		.057	
	Land Use Activity	Planning Period							
Model	j	1	2	1	2	1	2	1	2
	1	253.37	70.94	338.66	25.34	236.79	52.68	302.73	61.27
	2	197.15	24.90	160.80	73.21	194.70	20.67	173.44	60.56
	3	38.96	--	55.00	55.00	21.39	--	55.00	46.37
1	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	486.48	110.84	569.46	168.55	467.88	88.35	546.17	183.20
	5	1,784.24	--	1,667.91	--	1,807.45	--	1,691.63	--
	Open Space/ Other Dev.	2.98		2.26		3.24		2.31	
	1	265.46	98.55	364.00	--	225.11	138.89	259.52	104.49
	2	186.56	47.44	151.88	82.13	200.76	33.25	188.64	45.35
	3	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
2	Sub-total	522.02	215.99	585.88	152.13	495.87	242.14	518.16	219.84
	5	1,630.51	19.40	1,664.25	12.68	1,628.16	18.45	1,654.59	15.16
	Open Space/ Other Dev.	2.23		2.27		2.23		2.26	

Table 3.18

Allocation of Land to Various Uses by Period of Development and the Ratio of Open Space to Other Development for Risk Aversion $\phi = .01$

		Discount Rate							
		.05				.10			
		Damage Coefficient							
		.052		.057		.052		.057	
	Land Use Activity	Planning Period							
Model	j	1	2	1	2	1	2	1	2
1	1	232.12	99.49	339.06	24.94	233.07	83.70	302.35	61.65
	2	198.33	11.61	160.65	73.35	197.96	2.92	173.57	52.17
	3	55.00	--	55.00	55.00	55.00	--	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	500.45	126.10	569.71	168.29	501.03	101.62	545.92	183.82
	5	1,751.67	--	1,657.72	--	1,775.46	--	1,684.94	--
	Open Space/ Other Dev.	2.79		2.24		2.94		2.31	
2	1	264.17	99.83	364.00	--	223.87	140.13	259.77	104.23
	2	187.01	46.99	151.87	82.13	201.20	32.80	188.56	45.44
	3	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	521.18	216.82	585.87	152.13	495.07	242.93	518.33	219.67
	5	1,629.41	19.40	1,646.22	20.67	1,627.28	18.45	1,644.35	19.53
	Open Space/ Other Dev.	2.23		2.25		2.22		2.25	

Table 3.19

Allocation of Land to Various Uses by Period of Development and the Ratio of Open Space to Other Development for Risk Aversion $\phi = .02$

		Discount Rate							
		.05				.10			
		Damage Coefficient							
		.052		.057		.052		.057	
	Land Use Activity	Planning Period							
Model	j	1	2	1	2	1	2	1	2
1	1	246.92	102.60	337.10	26.89	264.79	58.74	315.45	48.55
	2	193.08	0.90	161.34	70.16	186.79	--	168.97	45.01
	3	55.00	1.65	55.00	55.00	55.00	--	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	510.00	120.15	568.44	167.05	521.58	73.74	554.42	163.56
	5	1,427.35	--	1,364.98	--	1,430.76	--	1,440.09	
	Open Space/ Other Dev.	2.26		1.85		2.40		2.00	
2	1	264.56	99.44	364.00	--	226.93	137.09	265.38	98.88
	2	186.88	47.12	151.89	82.13	200.12	33.88	186.68	47.33
	3	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	521.44	216.56	585.89	152.00	497.05	240.97	522.06	216.21
	5	1,463.71	19.40	1,434.61	20.94	1,466.00	18.45	1,436.94	19.70
	Open Space/ Other Dev.	2.00		1.97		2.01		1.97	

Table 3.20

Allocation of Land to Various Uses by Period of Development and the Ratio of Open Space to Other Development for Decision Model 3

		Discount Rate							
		.05				.10			
		Damage Coefficient							
		.052		.057		.052		.057	
	Land Use Activity j	Planning Period							
φ		1	2	1	2	1	2	1	2
	1	359.01	--	337.69	26.34	363.99	--	364.01	--
	2	151.87	82.13	161.15	72.85	151.87	82.13	151.87	82.13
	3	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
0.0	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	580.88	152.13	568.84	169.19	585.86	152.13	585.88	152.13
	5	1,655.76	10.24	1,647.05	14.47	1,649.47	15.35	1,650.32	13.75
	Open Space/ Other Dev.	2.27		2.25		2.25		2.25	

Table 3.21

Allocation of Land to Various Uses by Period of Development and the Ratio of Open Space to Other Development for Decision Model 3

		Discount Rate							
		.05				.10			
		Damage Coefficient							
		.052		.057		.052		.057	
	Land Use Activity	Planning Period							
ϕ	j	1	2	1	2	1	2	1	2
0.01	1	364.00	--	336.24	27.76	364.06	--	364.00	--
	2	151.87	82.13	161.64	72.36	151.88	82.13	151.87	82.12
	3	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
	4	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Sub-total	585.87	152.13	567.88	170.12	585.94	152.13	585.94	152.13
	5	1,655.76	10.24	1,643.53	16.18	1,643.57	18.261	1,652.17	13.82
	Open Space/ Other Dev.	2.25		2.25		2.25		2.25	

ϕ was assumed to be 0.01 the period 2 development was suggested to be in Region 2. Significant change occurred in the optimal solution beyond ϕ = 0.02 -- the allocation of land to open space in all regions declined. With high risk aversion assumed, some available land is left unallocated to a particular use (including open space).

3.5 *Additional Implications of Risk Aversion.* In general it is assumed that the floodplain occupant has an aversion to risk which is a function of the wealth of an individual occupant. Since planning of floodplains takes into consideration the community preferences and not the individual preferences, it may not be implausible to think in terms of some average level of risk aversion. Under such situations the analysis of choice of the decision-maker among alternative risky ventures assumes a critical importance. Various techniques for analysis of such decisions have been proposed. Among these, the Markowitz Mean-Variance Criterion has widely been used in spite of various criticisms brought against it. It has been shown that (E-V) analysis is valid when the statistical distribution is normal or where the utility function to be maximized is quadratic. In spite of these objections, mean variance analysis has been found to be useful though one has to be cautious in deriving conclusions based on E-V frameworks. To quote Samuelson [1967], "... In practice where crude approximations may be better than none, the two moment (E-V) model may be found to have pragmatic usefulness."

Some of the objections could be accommodated by applying a modified (E-σ) criterion proposed by Baumol [1963]. The process involves replacing σ by L where $L = E - \kappa\sigma$ is the lower limit of the confidence level. Firstly, in using such a criterion one needs not assume any distributional form. With the help of the Tchebycheff inequality one can arrive at the value of k in terms of the likelihood that the observation will fall beyond $E = \kappa\sigma$. Secondly, this criterion narrows down the possible efficient set arrived at through the (E, σ) criterion.

3.5.1 *E-V Decisions.* An exhaustive discussion of the empirical results of the E-V applications is not the purpose here -- the reader is referred to Tables 3.22 through 3.24 for some summary data in this regard. Briefly, the optimal solution did not include additional dams, although it did call for extensive flood proofing measures -- particularly in the highest risk zones. For purposes of illustration, Figure 3.1 depicts an E-V solution for this community with a five percent discount rate, damage coefficient set at its expected value, and no dams to be constructed. The solutions reveal that the expected value of the objective function can increase rather substantially from the most conservative set of decisions in terms of risk (measured by variance or standard deviation) without comparable increases in risk. However, land use assignment decisions intended to push expected value of economic rent above, say, twenty-three million dollars are faced with comparatively striking increases in variance for this application.

Table 3.22

Expectation and Variance of the Objective Function (Z^*) at Various Levels of Risk Aversion (ϕ) for Decision Model 1

Set	Discount Rate (r)	Damage Coefficient (a_h)	Risk Aversion (ϕ)	$E(Z^*)$ (million $)	$[V(Z)]^{\frac{1}{2}}$ (000 $)
1	.05	.052	.05	8.111	8.402
			.10	7.061	5.634
			.25	5.604	3.686
			.50	4.063	2.174
			1.00	2.973	1.193
2	.05	.057	.05	9.345	9.199
			.10	7.570	6.516
			.25	6.043	3.797
			.50	4.536	2.374
			1.00	3.224	1.342
3	.10	.052	.05	8.334	8.871
			.10	7.192	5.755
			.25	5.645	3.691
			.50	4.125	2.206
			1.00	3.009	1.263
4	.10	.057	.05	10.406	9.404
			.10	9.377	6.905
			.25	6.912	4.020
			.50	5.247	2.513
			1.00	3.868	1.526

Table 3.23

Expectation and Variance of the Objective Function (Z^*) at Various Levels of Risk Aversion (ϕ) for Decision Model 2

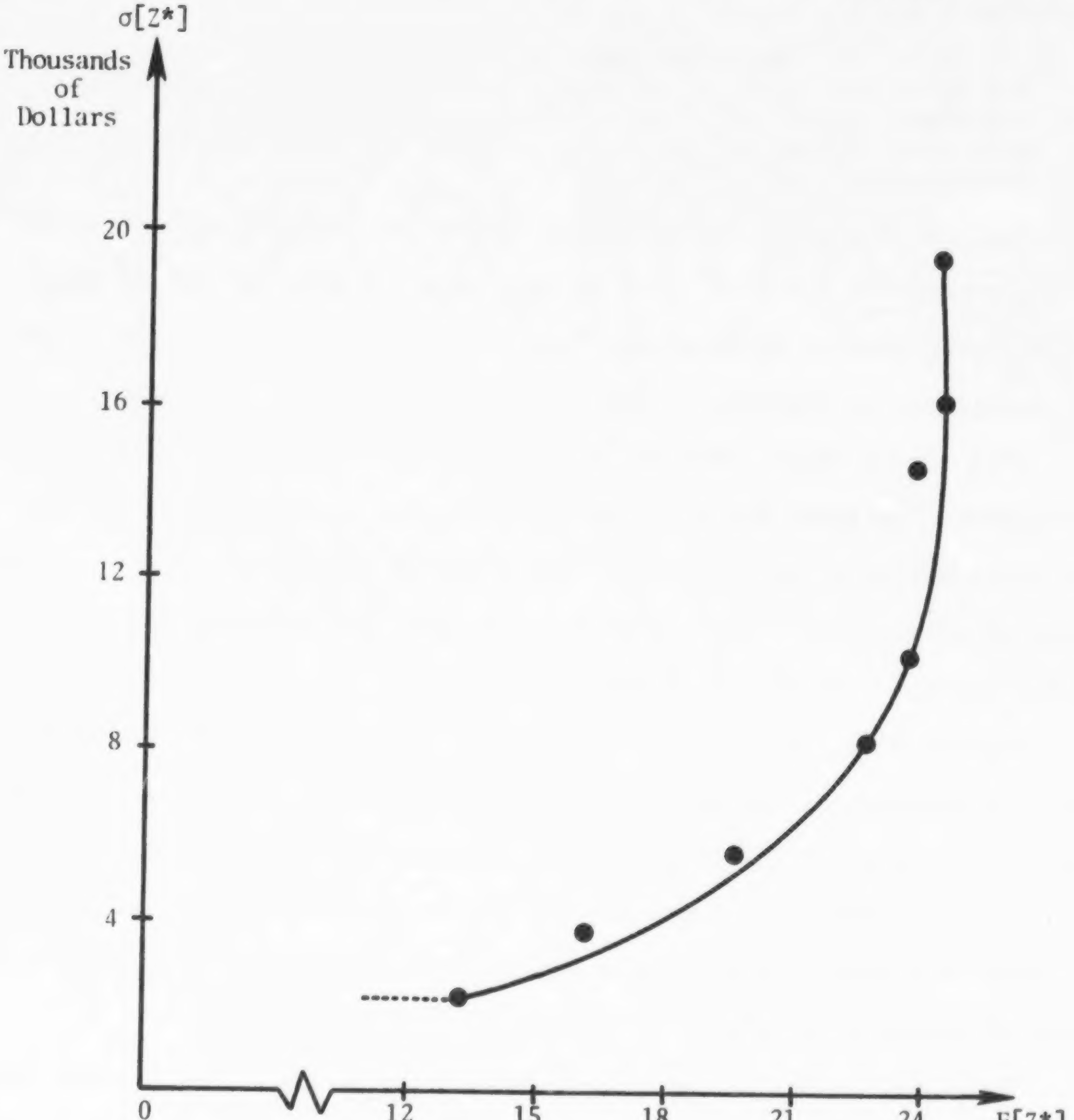
Set	Discount Rate (r)	Damage Coefficient (a_h)	Risk Aversion (ϕ)	$E(Z^*)$ (million \$)	$[V(Z)]^{\frac{1}{2}}$ (000 \$)
1	.05	.052	.05	23.685	10.242
			.10	22.947	8.392
			.25	19.685	5.711
			.50	16.228	3.913
			1.00	13.207	2.150
2	.05	.057	.05	13.703	10.090
			.10	12.577	7.708
			.25	9.536	4.654
			.50	7.133	2.745
			1.00	5.422	1.624
3	.10	.052	.05	21.867	10.230
			.10	21.134	8.384
			.25	18.000	5.683
			.50	14.582	3.528
			1.00	11.777	2.408
4	.10	.057	.05	12.961	9.743
			.10	11.763	7.573
			.25	8.884	4.637
			.50	6.463	2.681
			1.00	4.844	1.601

Table 3.24

Expectation and Variance of the Objective Function (Z*) at Various Levels of Risk Aversion (ϕ) for Decision Model 3

Set	Discount Rate (r)	Damage Coefficient (a_h)	Risk Aversion (ϕ)	E(Z*) (million $)	$[V(Z)]^{\frac{1}{2}}$ (000 $)
1	.05	.052	0.00	18.647	16.736
			.05	16.988	9.608
			.10	16.342	8.357
			.25	13.723	5.207
			.50	11.234	3.194
			1.00	8.987	1.962
2	.05	.057	0.00	19.170	16.727
			.05	17.494	9.620
			.10	16.842	8.365
			.25	14.257	5.289
			.50	11.726	3.263
			1.00	9.456	1.879
3	.10	.052	0.00	15.270	16.738
			.05	13.645	9.535
			.10	12.799	7.899
			.25	10.123	4.787
			.50	7.926	2.880
			1.00	6.072	2.180
4	.10	.057	0.00	15.608	16.642
			.05	13.986	9.589
			.10	13.131	7.938
			.25	10.441	4.810
			.50	8.181	2.886
			1.00	6.307	1.798

Figure 3.1
E-V Frontier with Mean (E[Z*]) in Millions of Dollars
and Standard Deviation (σ[Z*]) in Thousands of Dollars



4. Flood Management: Who Benefits and Who Pays

When the United States Congress passed the Flood Control Act of 1936, it directed

> "that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs." [74th Congress, 1935-1936, p. 1570].

The last line not only established benefit/cost analysis as a basic decision making tool for public resource decisions but also limited the analysis to total benefits in comparison to total costs. Questions of what groups in society receive benefits and pay costs were made legally irrelevant.

This act has become basic legislation for Federal involvement in resource management. The distribution of benefits and costs among groups in society has continued to be ignored in most federal and much state and local resource decision making. As a result, decisions are often highly beneficial to small groups but are socially sub-optimal.

Federal flood control action since 1936 provides an excellent example of such sub-optimality. During this period, annual flood damages have increased (Table 4.1) in spite of the national expenditure on floodwater control structures built to reduce flood damage. As will be demonstrated below, this relationship is a direct consequence of ignoring the distribution of benefits and costs of the selected method of flood control.

The objective of this paper is to examine the ultimate resting place among groups in society of benefits and costs of alternative flood management actions and to make comparisons among the alternatives.

Table 4.1

Flood Damage in the United States, in Current Dollars,
by Five Year Periods, 1925-1972

Period	Flood Damages (million dollars)	Retaining Structures
1925-29	$495	
1930-34	76	
1935-39	966	
1940-44	481	
1945-49	133	
1950-54	1680	
1955-59	1695	
1960-64	1151	
1965-69	2562	
1970	225	
1971	288	
1972	2163[a]	

[a] Includes damage only from Tropical Storm Agnes and the Rapid City Flood as reported by Kunruther, H., Recovery from Natural Disasters, American Enterprise Institute for Public Policy Research, Washington, D. C., 1973, p. 16. Total damages for 1972 have not yet been reported by the U. S. Weather Bureau.

Source: U. S. Weather Bureau, Annual Summary of Climitological Data. Up through 1965, as reported from this source by Dacy and Kunruther, The Economics of Natural Disasters, Free Press, New York, 1969, page 6.

4.1 *Basis of the Analysis.* The assumption on which this analysis is based is that changes in the market value of real estate on and off the floodplain constitute the final resting place of most benefits and costs of flood management actions (except those costs paid by the taxpayers). Changes in the cost of using floodplain land, including the cost of expected flood damage, influence the economic rent or net income obtained from the land which, in turn, influences the market value of the land. Floodplain land prices will rise whenever the risk of flood damage is physically reduced or shifted to someone other than the landowner and fall when a flood management program forces landowners to pay more of the costs of flood damage.

It is essential to recognize that the landowner who owns the land during a change in the flood management program (the "before" owner) is the one who sees the market value of his land increase or decrease. Once the land price has adjusted to the new net income situation, subsequent owners (the "after" owners) of the land are indifferent to the change. All the anticipated benefit or cost to the landowner has been capitalized into land value in a "one-shot-deal." Although both increases and decreases in land values are partially captured by society through changes in real estate and capital gain or loss taxes, the landowner is the primary gainer or loser.

As an illustration, the imposition of the Federal Flood Insurance Program will often require landowners to pay annual insurance premiums. This will increase the cost of operating the land, decrease net income, and in turn, reduce the market value of the land. If the land market is operating perfectly, the "before" owner will have suffered a one-time loss of capital value of his land. The "after" owner will pay the annual insurance premium but will have paid enough less for the land when he bought it to compensate for this added expense.

The analysis assumes a real estate market in which changes in net income from the land become capitalized into changes in land value. Although the real estate market has numerous imperfections, it does respond to perceived changed net income opportunities and the use of land value changes for the purposes of this paper is generally valid if the normal time lag for market adjustment is recognized.

Throughout the analysis, the pre-1927 valuation of floodplain land in relation to non-floodplain land represents a benchmark situation. This was prior to general Federal involvement in the construction of floodwater retaining and protection works and prior to federal disaster relief. Presumably, prior to this date, the value of floodplain land was discounted below the value of equivalent non-floodplain land by the perceived cost of expected damage from natural, uncontrolled flooding. Reference to pre-1927 conditions below will indicate a situation where floodplain land values are in perfect adjustment with the true natural flood damage risk of using these lands. The analysis is discussed in terms of deviations from this benchmark situation.

The incidence of costs and benefits of each major flood management alternative is discussed separately. The paper ends with a summary comparison among alternatives.

4.2 *Structures and Disaster Relief.* Since 1927, the Federal Government has gradually increased its responsibility for flood protection. This has involved construction of floodwater retaining dams and flood protection levees, and disaster relief when flooding does occur. The construction program is generally designed to eliminate a portion of the flood risk, not all of it.

To determine the beneficiaries of these protection and relief expenditures by taxpayers, the protected situation can be compared with the pre-1927 situation. These Federal expenditures will tend to reduce the cost of flood damage to the individual landowner and thus to increase his economic rent and the market value of his real estate. For urban uses which are already established on the floodplain, the one-time increase in real estate value will be based on the capitalization of the perceived reduction in average annual flood damage. If market actors overestimate the effectiveness of the dams and levees which often seems to be the case, the increase in real estate value will be greater than is justified by the actual damage reduction. The increase may be sufficient to eliminate the price differential between equivalent floodplain and non-floodplain land, indicating that the market perceives complete protection from flood damages.

The increase in the value of developed land, however, is likely to be modest compared to that of land which had remained undeveloped because of its high perceived flood risk but which now has a low enough risk to permit urban development. In a growing community, such land will change from low value undevelopable land to high value developable land. Moreover, it will often be well located relative to its development potential. The owners of such land find that their land has developed an urban use potential as a result of taxpayers' expenditure on flood retaining structures and that its value has increased substantially.

Some benefits are distributed more widely among community residents. An example is the possible shorter driving distances to a shopping center on a floodplain site instead of an alternative non-floodplain site. Major benefits of the flood control structures, however, will accrue to or be appropriated by the relatively few individuals who own floodplain real estate as "before" owners. Some will accrue to owners of already developed land while most will go to owners of land which changes its development potential as the result of public expenditure.

Owners of non-floodplain land in the community are likely to experience some decline in the value of their land as the supply of developable land increases with no change in the demand for such land.

The expectation of disaster relief has a similar impact. To the extent that the real estate owner expects the taxpayer to pay for flood damages that do occur, the real estate market will reduce the discount for flood risk and thus increase the market value of floodplain real estate.

Since increases in the value of undeveloped land often involve large amounts of money, the incentive is strong for floodplain landowners to persuade the federal government to construct protection works. The result is extensive urban development of floodplain land which is flooded when a larger-than-design flood occurs. By the time of such a flood, however, the major beneficiaries of the federal expenditures, the "before" owners, have sold their land and taken their windfall gain. The damaged owners will have paid a price which reflects the reduced expected damage and possibly even more if the market over-estimated the effectiveness of the structures.

4.3 *Flood Proofing.* Flood proofing involves the design modification of a structure located on the floodplain with the goal of reducing damage when a flood occurs. It includes structural changes in existing buildings and changes in the structural specifications of new construction.

Except for some income tax benefits, the cost of flood proofing is paid by the individual real estate owner. It is a one-time payment in return for which the owner will experience lower damages from a flood than would otherwise be the case. Damages may be reduced to zero in smaller, more frequent floods and on the outer edges of the floodplain. Flood proofing can either be voluntary on the part of an individual owner or required of all owners in a specified floodplain through zoning or building codes.

The distributional impact of flood proofing depends on the pre-proofing situation and on whether the proofing is voluntary or mandatory. Two extreme pre-proofing situations provide the basis for the following discussion.

Starting from a pre-1927 situation with voluntary flood proofing, the owner may invest in proofing in an effort to reduce his potential flood damages. His decision to install flood proofing is based on a comparison of average annual costs of the flood-proofing installation with the average annual reduction in flood damages to be achieved by the flood proofing. If the costs of proofing are less than the expected reduction in damages, he can benefit. If the real estate market is operating perfectly, his property will increase in value in an amount equal to the capitalized decrease in expected flood damage. The increase in value is related to the decrease in expected flood damage not the cost of flood proofing. With scattered and voluntary flood proofing, however, the market probably will not recognize the true benefits of the proofing and consequently, the property will increase in value less than the true worth of the flood proofing. This is especially likely to be the case when government disaster relief programs are active. If the flood proofing owner continues to use his property, of course, he receives the ongoing benefit of the flood proofing in return for the investment made in it. When disaster payments are available, however, he has, in effect, voluntarily accepted some flood damage costs that would otherwise be borne by the taxpayer.

If flood proofing is mandatory, again assuming pre-1927 conditions, individual owners still pay the cost of installation. The market, however, is more likely to recognize the benefits of the flood proofing and real estate values will be adjusted upward to reflect the decrease in damage potential. If the mandatory order includes areas where proofing is inappropriate (will cost more than the value of the damage reduction), the landowner will be required to pay more than the proofing is worth to him in terms of either damage reduction on increase in property value [Aklilu and Willis, 1973].

In areas where flood proofing is appropriate, however, and where the market identifies the improved damage risk situation, the landowner can be indifferent to or receive net benefit from flood proofing. It will be an extra cost but, with perfect adjustment by the market, his property value will be increased enough or more than enough to compensate him.

If the market perceives that flood risk has been reduced to near zero by Federal activities, the landowner's view of flood proofing differs from that discussed above. In the perception of the market, nothing is to be gained by proofing against a non-existing damage potential. The individual might still voluntarily flood proof his property because he perceives a greater risk than does the market but this will have no effect on the market value of his property. In the event of a flood, his proofing will again save the taxpayers at least part of the cost of disaster payments to him.

If flood proofing becomes mandatory under conditions of perceived near zero flood risk, the landowner will experience a decline in the market value of his land. The mandatory flood proofing associated with the current Flood Insurance Program can have this effect. It will be viewed as an increased cost of using the site which will reduce the net income and thus the market value of the land.

The flood proofing and other parts of the Flood Insurance Program will be moving the situation toward the pre-1927 benchmark where the flood disability of the land was adequately reflected in its market value. The individual who reaped the windfall benefits from the reduced perceived flood risk resulting from federal structure and relief programs on the same watershed, however, is seldom the same individual who sees the value of his land declining again toward the pre-1927 situation. The owner who sees his land value decline will commonly be an "after" owner in terms of the value impact of structures and relief programs. He sees the mandatory flood proofing as a threat to the value of his property even though it moves the total situation toward the pre-1927 relationship.

The above discussion applies equally to both old and new construction since flood proofing will be an added expense in both cases. Equivalent proofing may have a lower cost with new construction, however, since it can be incorporated at the time of construction.

4.4 *Watershed Land Treatment.* The conscious management of non-floodplain watershed land to reduce runoff of floodwaters can often partially reduce flood peaks. Land management to accomplish this include improved soil structure, more vegetative cover, storage of water in surface depressions and irregularities, and terracing and contouring cropland.

Since more watershed land is privately owned, at least in the eastern part of the country, the private landowner is the person who must make, implement, and pay for the decision to manage his land with the objective of minimizing downstream flood peaks. This objective can sometimes be realized as a by-product of other management objectives such as erosion control but will often involve specific action directed at reducing runoff.

The benefits of such action accrue to owners of floodplain land. The benefits take the form of lower actual average annual flood damage and, if the market recognizes this as a long run increase in protection, an increase in floodplain real estate values. The situation is similar to that of floodwater retaining structures and disaster relief.

The watershed landowner, however, must pay the cost of whatever action is taken on this land. He receives no benefit when the action involved is specific to flood peak reduction. Some land management actions can be cost-shared through Federal programs but this divides the cost between landowners and taxpayers with the beneficiaries down on the floodplain still paying nothing. Not surprising, land management for flood peak reduction is uncommon except as a by-product of management focused on other objectives. This approach to the public objective of flood damage reduction has failed because the distributional issues were not recognized in program design.

4.5 *Floodplain Zoning.* Although floodplain zoning does not necessarily remove the right of urban development from specified areas of the floodplain, the following analysis assumes this removal to be a common feature of most such zoning.

When floodplain zoning is imposed, one result is a constraint on the normal action of market forces by removing specified areas of undeveloped floodplain from the supply of developable land. The market value of the land zoned non-developable will drop to the level of its value for the most profitable permitted use, perhaps agriculture. Individuals who own the land at the time zoning is imposed will experience a capital loss as "before" owners.

For land that is far from current development pressures or has locational or physical characteristics unfavorable for development, this loss will be minimal. On land with high development pressures, this loss of capital value can be substantial especially where the market perceives a low flood risk as a result of Federal structural programs.

Much of the lost value has been created by development pressures and structural programs of society rather than by land improvement by owners so that it can be argued that society, through zoning, is only taking what it created. This argument is particularly unacceptable, however, to owners who have recently purchased such land at high development and low risk prices with the expectation of using it for development. The socially created value appreciation on such land has been experienced and liquidated by "before" owners.

When some floodplain land is withdrawn from the supply of developable land by zoning, no related change in the demand for such land is expected. The restriction in supply with no change in demand will cause prices of developable land on and off the floodplain to rise and owners of this land will experience capital appreciation. The price of this land will continue to be influenced by its suitability for development but prices will be higher than without floodplain zoning.

If tax assessors are cognizant of these value changes, the real estate tax burden will shift in the same direction as the value changes. If the assessed value of developable land increases less than the loss in assessed value of the zoned land, however, all other property in the community will experience some increase in taxes as a result of the zoning.

The above discussion emphasizes the capital transfer between two groups of landowners resulting from floodplain zoning. In addition, there are numerous costs and benefits which are external to individual landowners.

Perhaps the most important external cost, at least in the eyes of some residents of the community, is the impact on community development. As the price of developable land rises, development becomes generally more expensive.

Zoning may also eliminate those sites in the community which have become most desirable as a result of government reduction and subsidy of flood damage. The result can be a decrease in the relative attractiveness of a community compared with alternative communities, states, or even countries and a decrease in the rate of economic growth of the community. This will mean lower income than would otherwise be the case for members of the community who benefit from economic growth including contractors, merchants, lawyers, real estate brokers, and similar individuals.

Lower income people may experience added costs from such zoning. In many communities, housing for such people is concentrated on the floodplain and elimination of some floodplain land from the supply of buildable land can have a stronger impact on the supply of land for low income housing than on the supply for housing in general. If expansion of low income housing is limited by this zoning increases in values and rents of existing housing can be expected, while the zoning may have only modest impact on the housing market for moderate and higher income groups.

In some circumstances, floodplain land will be more desirable than alternative sites for development even after the added cost of flood damage is correctly included in the calculations. If zoning forces a suitable use to a less desirable site, the extra costs of the less desirable site will be borne broadly by the community both as patrons of, say, a shopping center and as taxpayers. It should, perhaps, be added that a fully informed zoning decision would permit development of such a floodplain site where the social benefits of development are enough greater than those of an alternative site to more than cover the cost of expected flood damage [Smiarowski, Willis, and Foster, 1975].

The would-be owners and users of the zoned floodplain land will experience both costs and benefits from the zoning. Their land costs will generally be higher at equivalent alternative sites but they will escape all individual costs associated with an actual flood such as possible loss of life, damage to property, and personal fear and hardship. These costs may not be recognized when planning to locate on the floodplain or, if recognized, may be less than the benefits of the floodplain site. Nevertheless, they are important costs that are avoided by staying off the floodplain.

Although the cost of zoning establishment and enforcement may cause some upward pressure on taxes, the basic purpose of floodplain zoning is to reduce the public and private costs of floods. To the extent that it achieves this purpose, the long-run impact on taxes will be downward. The major impact will be on Federal taxes, but local taxes should also decline, especially if the zoned land has high flood risk which would involve, if developed, frequent local emergency and rehabilitation expenditure.

A generally accepted benefit of this zoning is the preservation of undeveloped open space in the community. Many people in most communities will consider this preservation to be a distinct enhancement of the living environment in the community. This benefit is further enhanced if some or all of the zoned land is developed for general outdoor recreation and park uses which are compatible with floodplain conditions. If these are public facilities, most members of the community will benefit from their use, although some may raise a question about the equity of a procedure by which the value of the land is lowered through zoning and then the land purchased for public recreational purposes at the post-zoning lower price.

Those who favor preservation of open space will also tend to view the possible slower economic growth discussed above as a definite benefit of zoning.

If the zoned floodplain is used for agriculture, a generally compatible floodplain use, the farmers are likely to have a mixed reaction. While they will experience a loss of actual or potential land value appreciation, those who wish to continue farming will find it easier to do so. The zoning should reduce and hold down their real estate taxes and tempting offers for their land will no longer disturb them. The more explicit statement about their location on the floodplain may cause modified management practices to minimize potential flood damage. The actual flood risk, of course, is unchanged by zoning.

In summary, community groups directly or indirectly hurt by eliminating sections of a floodplain from the supply of developable land by zoning include owners of the land so zoned, individuals benefiting from general economic and population growth in the community, low income people who find housing on the floodplain, and all who help pay the extra cost of less suitable sites. Those benefiting from this zoning include owners of other developable land, those favoring less growth, all who value preserved open space and outdoor recreation, farmers who wish to continue farming, taxpayers, and some of those who would have moved onto the floodplain if not prevented by zoning. Clearly, these groups overlap and one individual may simultaneously be a member of several groups of both gainers and losers.

4.6 *Floodplain Insurance.* Partly in recognition of the failure of the structure and disaster relief programs to reduce average annual flood damages on a national basis, Congress enacted the flood insurance program that is currently passing through the process of extending coverage to most floodplain land in the nation. Insurance coverage itself does nothing to change the amount of actual physical flood damage although the flood proofing and land use controls associated with the program are designed to do so. It is primarily designed to shift the cost of flood damage from the taxpayer back to the landowner where it was in the pre-1927 situation. As such, it will have a distributional impact similar to that of flood proofing discussed above.

If an unsubsidized insurance program were to be introduced on a voluntary basis into a pre-1927 situation, landowners could protect themselves from flood loss by buying a policy. If the actuarial calculations are correct, in the very long run the annual cost of the insurance will equal the average annual flood damages (except for insurance administration costs) and the landowner will, in the meantime, be protected from large losses. He will be changing an unknown loss into a known payment. Since the availability of insurance reduces the risk of using the floodplain, the market could reflect this through somewhat increased floodplain land values but this impact would probably be slight.

If voluntary insurance is made available where perceived flood risk has been reduced to near zero by Federal programs, the insurance premium will be considered an unnecessary added expense by landowners and they will have little interest in buying the insurance. The recent voluntary program illustrates this. It was primarily available in areas where Federal structural and disaster relief programs have substantially modified flood risk and few policies were sold.

A mandatory program of flood insurance imposed on a pre-1927 situation will increase annual operating costs of floodplain sites but reduce the average annual risk of financial loss. Land values will increase somewhat because of the lower risk.

The current semi-mandatory insurance is being imposed mostly where the market sees flood risk as substantially lower than the pre-1927 benchmark. The lower risk perception results either from Federal construction and disaster relief programs on the particular watershed and/or market ignorance of the true flood risk. The latter situation is common on floodplains of smaller streams which flood infrequently and where no Federal activity has called attention to potential hazard but ignorance may also play a role among major streams.

As discussed above, the market result of perceived low risk (whether it is a true perception or not) is an increase in the value of floodplain land as compared to the benchmark situation. When semi-mandatory flood insurance is imposed, the landowner sees it as an extra cost of operation which will reduce his economic rent and his land value. Since the owner of the land during the imposition of the insurance has commonly purchased his land at high prices following market adjustment to either Federal protection programs or ignorance of true flood risk, he sees the insurance program as a threat to the value of his capital assets.

One important result of the flood insurance program is the careful determination of the floodplain and various risk levels on it in such a way that its location is rather forcefully brought to the attention of the public. Once the permanent actuarial maps are prepared, ignorance as a factor in the pricing and use of floodplain land should decline dramatically. Where ignorance of true risk has been a factor, floodplain land prices should adjust accordingly, usually in a downward direction.

The temporary insurance program, which is in effect until permanent actuarial maps are prepared, uses standard subsidized premium rates with "best estimate" maps. The distributional impact of this temporary program will differ in some respects from that of the permanent program discussed above. Where the subsidized rates are actually below the actuarial rates, land values will decline less than with the actuarial rates because the taxpayer is still taking some of the risk through the subsidy. Some have predicted that the time gap between the initiation of the temporary and permanent programs will stimulate floodplain development as owners seek to partially protect their land values by qualifying for subsidized rates.

Areas that are excluded from the floodplain on the temporary map are not directly influenced by the temporary program. However, if a landowner expects his land to be included in the floodplain on the permanent map, it would be in his interest to sell or to develop and sell his land prior to the drawing of the permanent map.

4.7 *Summary*. The implicit criteria of equity in floodwater management accepted here is that land with a flood risk disability should bear the cost of use with this disability in the same way that infertile land or poorly located sites bear the costs of the particular disability. These costs are generally expressed in terms of lower land values than equivalent land without the disability and the amount of the lower land value is related to the extra cost or decreased income from using the land with the disability, capitalized into a decrease in land value.

Government flood management programs in the past have tended to shift the cost of the flood disability from the land to the general taxpayer. This approach has received strong support from floodplain landowners and the political process has successfully allocated large amounts of Federal money to flood control structures and disaster relief. The result has been increased floodplain land values and expansion of urban uses on floodplains.

The socially unacceptable results of these policies have gradually become clear following substantial floods in recent years. This has stimulated interest in putting the cost of the flood disability back on the land so that this cost will be internalized in floodplain use decisions and the value of the floodplain land correctly adjusted to its disability.

One alternative to accomplish this would be for government to end its involvement in flood management. This alternative has, apparently, not been considered. Instead, programs of insurance, zoning, and flood proofing are being developed which put the cost of flood risk back on the land but with various types of guidance and use controls designed to protect both the landowner and society. The land loses market value in the process but equity is improved and, perhaps more important, the stimulus for socially sub-optimal flood management decisions is reduced.

5. Conclusions

The main conclusion at this point is that it is clearly feasible to develop an operations research framework, featuring the floodplain management alternatives considered here, which: treats rent or land values as a function of level of development; is capable of considering interrelationships among uses; is capable of formally reflecting planners' aversion to uncertainty; and which provides for early period decisions which are conditional upon forecast later period situations. It is in these latter aspects that the approach developed here appears superior to the previous operations research approach -- Day's recursive linear programming (RLP) framework.

While the RLP approach is capable of recognizing the impact of previous period development on economic rent (land values) for later periods, the quadratic programming (QP) approach permits this recognition for decisions within a period as well. To be sure, the greater complexities involved in solving QP problems may involve greater expense and/or increased levels of aggregation (fewer and longer planning periods; fewer and larger regions within the floodplain) and possible aggregation bias. Which approach is most useful for a particular situation would seem to be an empirical question.

Secondly, while the RLP approach is virtually incapable of treating interrelationships among assignments, these can be treated conveniently in the QP approach -- although the test problem was not set up to do so. The econometric estimation of the nature of these relations for inclusion in the framework has not been well-developed, however. This would appear to be a fruitful area for further research.

Third, the simultaneous solution of all periods, with future situations impinging upon current decisions, in the QP approach would appear to provide improved solutions over the forward solution RLP process. The argument has been made, however, that this RLP approach permits advantage to be taken of the more certain data of the near future so that immediate plans can be formulated with relative confidence. The disadvantage, of course, is that a weight of zero is given to data (estimates) for later periods. In any event, for the QP framework, the greater uncertainty regarding the more distant future situations -- at least with respect to objective function values -- is reflected in higher variances and covariances in Ω of (6). These are then capable of more properly discounting future uncertainty with respect to these parameters.

The usual limitations of mathematical programming models apply here, of course. Dynamic programming is the ideal theoretical approach for this type of problem, but as is often the case, the numbers of state variables involved render the method intractable for problems of this size.

As a final conclusion, Day's opinion that optimizing approaches apparently have the potential for improving damage control planning is supported. An additional judgment is extended that while efforts to improve the existing formulations -- Day's and the present model -- will probably be productive, the greatest benefit will probably arise from efforts to quantify and estimate the components of these models. Efforts to estimate the interrelationships among assignments will be one such breakthrough. Along these lines, recent efforts by Freeman and by Rosen on methodology for estimating land values will permit greater precision regarding the objective function parameters than has existed to date. With these sorts of improvements, it is not unreasonable to expect frameworks such as the one developed here to provide improved damage control planning for a wide variety of floodplain (regional) situations.

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Appendix A

Knowledge of two points on the demand function -- one corresponding to the current selling price of land and the other given by Smiarowski [1974] -- and the assumption of a linear demand function, enabled the estimation of the slope of the demand function for each land use category. As indicated earlier, it was assumed that the slope was constant over all the regions and the differences were reflected in the intercepts only.

Rent functions follow directly from these (inverse) demand functions. Making use of the capitalized form of the differential rent, capitalization of rent represents summation of discounted economic rents over time. Assuming the value of the land constant over periods, the rent can be determined by using a formula

$$R_{ijt} = \sum_{t=1}^{\infty} [r_{ijt}/(1+E)^t] = r_{ijt}/E$$

Here we have assumed E = .10 and r_{ijt} is proxy for expected economic rents.

The coefficient vectors for one of the sets and matrices corresponding to the objective function (2.6) and the restraints (2.1) and (2.2) are presented below.

$$A = \left|\begin{array}{rrrrrrrrr}
14309 & 11522 & 11104 & 12125 & 9339 & 8939 & 14707 & 10631 & 10003 \\
37933 & 21737 & 19308 & 35838 & 19638 & 17309 & 46639 & 22951 & 19307 \\
52561 & 17561 & 12311 & 53880 & 18881 & 13849 & 71373 & 20077 & 12311 \\
50887 & 35823 & 33564 & 45482 & 30418 & 28253 & 57334 & 35304 & 31914 \\
3300 & 3300 & 3300 & 3300 & 3300 & 3300 & 3300 & 3300 & 3300 \\
\hline
13008 & 10475 & 10095 & 11023 & 8490 & 8126 & 13370 & 9665 & 9094 \\
34485 & 19761 & 17553 & 32577 & 17853 & 15736 & 42399 & 20865 & 17552 \\
47783 & 15965 & 11192 & 48982 & 17165 & 12590 & 64885 & 18252 & 11192 \\
46261 & 32567 & 30513 & 41347 & 27653 & 25685 & 52121 & 32095 & 29013 \\
3000 & 3000 & 3000 & 3000 & 3000 & 3000 & 3000 & 3000 & 3000
\end{array}\right|$$

The line in the matrix separates the two planning periods. Rows in each period correspond to uses (j) and the columns to three flood frequency zones in each region i; $i = 1, 2, 3$.

The matrix of slopes B in (2.6) is given by a symmetric matrix of the order 90, whose non-zero elements are b_{jt} where

b_{j1} = 2.5 7.1 3.1 11.3 0.1

b_{j2} = 24.7 70.5 31.2 113.2 1.4

The problem is restricted by 21 constraints. Six of these correspond to the land availability in three regions each having two flood frequency zones and the other fifteen relating to land availability restrictions for each use together with the population growth restraints. As such, we split these restrictions into two sets, P_1 and P_2. These correspond to p_{it} of (2.1) and p_{jt} of (2.2).

P_1 = 1162, 45, 207, 470, 6, 18, 80, 108, 80

P_2 = 164, 168, 55, 15, 918, 73, 20, 55, 15, 494, 127, 46, 268, 3500, 7000

P_2 contain some restrictions that need mention here. We have restrained the industrial development and commercial development in each time period to 55 acres and 15 acres, respectively. This constraint was to take care of desired development that keeps pace with need. Again, the last two constraints refer to population growth projected for two periods. This was thought feasible so that the residential development does not exceed the growth of population in the town. On an average, an acre devoted to single family homes was considered to accommodate 4.4 persons and an apartment complex on one acre would take care of 12.5 persons. These were the coefficients used for the restraint formulations.

Appendix B

CALCULATION OF DAMAGES

The elements of the A vector of (2.6) includes the damages caused by flood to different land use activities and these vary among flood frequency (risk) zones. For a given flood depth d, the flood damages to a structure bear a constant proportion to its market value M. Thus the damage depth function takes the form:

$D_{ij} = | a_h M_j \, di | B$, where

M_j = Market Value of the structure j
di = Expected level of flood depths in feet in zone i
B = $[1-1/(1+r)^t] \div r$
a_h = Constant of proportionality, called damage coefficient
D_{ij} = Present value of the damages to j^{th} structure in the i^{th} region.

Homan & Waybur [1960] found that the value of the damage coefficient to be approximately .052 on the basis of the empirical observations. Since this coefficient a_h of the flood damage function is known with a rather substantial degree of uncertainty, we have allowed it to vary. In this study, it takes two values, i.e., .052 and .057. In the absence of flood proofing or other flood control measures, these damages will be costs to the floodplain occupants and as such will be subtracted from the economic rents to give net economic rents.

CALCULATION OF COSTS OF FLOOD PROOFING

In the case of flood proofed structures, these damages would enter as benefits and the cost of flood proofing will be subtracted. Cost of flood proofing the structures is linearly related to the market value of structures. In the present study we considered only one level of flood proofing, i.e., the one that corresponds to the expected level of flood depths. Using James' [1966] formulation, cost of flood proofing was calculated using the following relation:

$Cij = [e_h M_j P_i]$, where

e_h = Cost Coefficient (Following Sheaffer [1960] we have taken e_h to be .037).

Mj = Market Value of structure j

Pi = Expected level of flood proofing.

Costs are compounded with an interest rate equivalent to market rate of interest for the length of project period, i.e., 50 years. As such

$C^*ij = Cij\ (1 + r)^t$

where r is market rate of interest.

Appendix C

Flood Proofing Measures

Measure	Material Protected	Class of Measure	Pre-requisites: Structural	Pre-requisites: Hydrologic
Seepage control	St-Co	P-C	Well constructed	None
Sewer adjustment	St-Co	P-C	None	H-W
Permanent closure	St-Co	P	Impervious walls	H-S
Openings closed	St-Co	C-E	Impervious walls	H-S-W
Interiors protected	St	P-C	None	S-W
Protective coverings	St-Co	P-C-E	None	H-W-F
Fire protection	St-Co	P	None	None
Appliance protection	Co	E	None	S-W-V
Utilities service	Co	P-C-E	None	S-W-V
Roadbed protection	St	P-E	Sound structure	H-W-V-D
Elevation	St-Co	P-C-E	Sound structure	S-W-V-F
Temporary removal	Co	E	None	W-F
Rescheduling	Co	E	Alternatives	W
Proper salvage	Co	-	None	None
Watertight caps	Co	P-C	None	W
Proper anchorage	St-Co	P-C	Sound structure	S-W-V-D
Underpinning	St	P	Sound structure	V
Timber treatment	St	P	None	None
Deliberate flooding	St-Co	E	None	None
Structural design	St-Co	P	Design	H-S
Reorganize use	Co	P	Alternatives	None

P = Permanent
C = Contingent
E = Emergency
St = Structure
H = Hydrostatic
S = Stage of flood
W = Warning
Co = Contents
F = Flood-to-peak interval
V = Velocity of flow
D = Duration of flood

Source: Scheaffer, J. R. [1960].

Appendix D

MONTE CARLO TECHNIQUE OF CONSTRUCTING
VARIANCE-COVARIANCE MATRIX Ω

For introducing 5 percent variation in economic rents/prices, use of unit normal deviates was made. Assuming the disturbance of the rent function (U) to follow the normal distribution with $E(U) = 0$ and with the help of unit normal deviates, a variance covariance matrix of the order (15 x 15)* whose diagonal elements corresponded to the unit variance was constructed. Assuming the prices/rents to vary to the extent of 5 percent of the expected prices, we forced this variation into $F(UU')$. That is, unit normal deviates gave us a variance-covariance matrix as:

$$E\,[UU'] = \begin{bmatrix} 1 & U_{12} & U_{13} & U_{14} & U_{15} & \cdots & U_{1,15} \\ & 1 & U_{23} & U_{24} & U_{25} & \cdots & U_{2,15} \\ & & 1 & U_{34} & U_{35} & \cdots & U_{3,15} \\ & & & 1 & U_{45} & \cdots & U_{4,15} \\ & & & & 1 & \cdots & U_{5,15} \\ & & & & & \cdots & 1 \end{bmatrix}$$

where U_{ij}; $i \neq j$ are covariance terms and $U_{ij} = 1$; $i = j$ are variance terms. Assuming that $\sigma^2_{ij} = 5$ percent of prices/rents, the matrix Ω is obtained by constructing a variance-covariance of transformed residuals U^* such that U^*

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* We had fifteen different price/rent structures, i.e., five land uses in each of the three regions.

has no mean zero and variance σ (which is assumed to be 5 percent of prices/rents). This matrix $\Omega = [\sigma_{ij}^2]$ corresponds to the matrix Ω of (2.6).

Appendix E

ESTIMATION OF BENEFITS DUE TO DAMS

The probability of a flood of given dimensions is expressed in terms of a flood frequency. If a flood of a given magnitude has been recorded only once in 50 years, it is said to have a frequency of 50 and is called a fifty-year flood. Floods are usually measured by their maximum rate of discharge of water during the peak period or peak instant. The rate of peak discharge is measured in cubic feet per second. The frequency or percent change of occurrence of peak discharges have been calculated by the U.S. Army Corps of Engineers and the natural peak discharge frequency relationships determined. Damages from floods depend on the number of feet by which the river exceeds its banks called the flood stages or flood depths. Dams may not altogether eliminate damages but may reduce the flood stages. In other words it may help in regulating the flood water in such a way that the 100 year flood is transformed into a 50 year flood. To be precise it may reduce the level of risk in each risk zone and in turn may help in reducing damages which can be said to be the benefits due to dams. We have taken recourse to this way of calculating benefits due to dams. A peak discharge frequency curve for Farmington River is plotted in Figure A-1. A dam of the specification of Coolbrook at Farmington was assumed to reduce the peak discharge of Farmington River by 20 percent. Thus the peak discharge frequency was lowered by 20 percent. This was used to calculate the probability of occurrence of a flood of previous depth. These were lower than the corresponding probabilities of occurrence of flood before dams. These probabilities are used in calculating the expected level of flood depths in each risk zone in each region. The damages were then calculated as explained in Appendix B, but now expected flood depths were lower than before dams. The difference between the damages calculated before installation of dams and after were the benefits due to dams.

Table A-1

Peak Discharge Data for Farmington River Connecticut
(Peak Discharge In Cubic Ft. Per Second)

Exceedance Frequencies		Peak Discharge		Prob.
Years	Per 100 Years	Before	After	
2000	.05	168,000	134,500	.0005
1000	.10	132,000	105,600	.0010
400	.25	93,000	74,400	.0025
200	.50	70,000	56,000	.0050
100	1.00	52,000	41,600	.0100
80	1.25	48,000	38,400	.0125
67	1.50	44,000	35,200	.0150
50	2.00	38,000	30,400	.0200
33	3.00	32,000	25,600	.0300
20	5.00	25,000	20,000	.05001
10	10.00	18,000	14,400	.1000
5	20.00	13,000	10,400	.2000
3.3	30.00	10,300	8,240	.3000
2.5	40.00	8,700	6,960	.4000
2.0	50.00	7,700	6,160	.5000
1.0	99.60	5,700	4,560	.9960

Source: Comprehensive Water and Related Land Resources Investigation, CONNECTICUT RIVER BASIN, Army Corps of Engineers, Vol. II, p. C-35, June 1970.

Figure A-1

Peak Discharge - Frequency Relationship
Farmington River, Connecticut